Long-range Rydberg-blockade entangling gate mediated by auxiliary atoms

Alexandre Cesa and John Martin

Institut de Physique Nucléaire, Atomique et de Spectroscopie, CEA/R, Université de Liège, Bât. B15, B - 4000 Liège, Belgium

Introduction

Two-qubit entangling gates between nearest neighbour qubits encoded in the ground state manifold of neutral atoms in a lattice can be implemented using Rydberg Blockade [1]. However, as Rydberg blockade becomes less effective with interatomic distance, such protocols fail for atoms separated by a few or more lattice sites. In this work, we propose a protocol implementing CZ and CNOT gates between qubits arbitrarily far apart in the lattice [2].

\[ U_{CZ} = \left| 00 \right> \left< 00 \right| - \left| 01 \right> \left< 01 \right| - \left| 10 \right> \left< 10 \right| + \left| 11 \right> \left< 11 \right| \]
\[ U_{CNOT} = \left| 00 \right> \left< 00 \right| + \left| 01 \right> \left< 10 \right| + \left| 10 \right> \left< 11 \right| + \left| 11 \right> \left< 11 \right| \]

Results and discussion

Gate fidelity : imperfect blockade

- Gate error proportional to probability of double excitation \( F_{\text{pro}} \propto \Omega^2/U^2 \)
- Process fidelity \( F_{\text{pro}} = 1 - \alpha \left( \frac{U}{\Omega} \right)^2 \)

with \( 0.1 \leq \alpha \leq 2 \) a constant whose value depends only on \( n_A \) and \( U_{\text{nClad}} \)

Gate Fidelity : effects of dissipation

- \( U_{\text{r}}/\Omega = U_{\text{r}}/\Omega = 200 \Rightarrow 1 - F_{\text{pro}} < 10^{-4} \)
- \( \gamma_0 = \gamma_1 = \gamma/2 \) and \( \gamma_\Lambda = \gamma \)

CNOT

\[ F_{\text{pro}} \approx 1 - \frac{E_{\text{eff}}}{2} \]

dots : process fidelity \( F_{\text{pro}} \).

crosses : lower bound on process fidelity as given by Hofmann [4].

Comparison with sequence of nearest neighbour CNOTs

- CNOT between qubits separated by \( n_A = 1 \) other qubits using sequence of nearest neighbours CNOTs [5] \( \Rightarrow \) process fidelity \( F_{\text{pro}} \)

Protocol

- Strong Rydberg blockade regime \( U \gg \Omega \) \( \Rightarrow \) conditional dynamics [1]
- All ancillary atoms initially in \( \left| 0 \right> \)

\[ A_1 \]
\[ A_2 \]
\[ \vdots \]
\[ A_{n_A-1} \]
\[ A_{n_A} \]
\[ T \]

- Dipole-dipole interaction between atoms in Rydberg state \( \left| \gamma_0, \gamma_1 \right> \)
- Dissipation of atoms excited to Rydberg states \( \Rightarrow \) master equation

Perspectives and experimental considerations

- Optimized pulses to improve process fidelity
- Experimental implementations

- Same species for both qubit and ancillary atoms [6,7,8]
- Two different atomic species for qubit and ancillary atoms [9]