Optical Hyperfine Qudit Gates in Trapped Atoms

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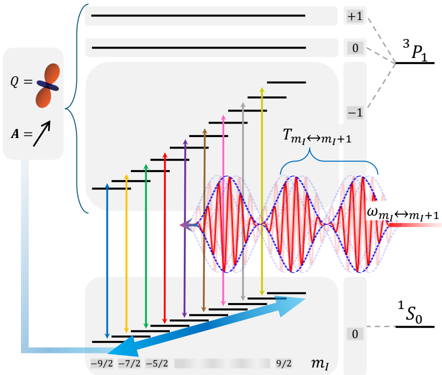

Fig. 1: Illustration of optical transitions accross all $^1S_0$ hyperfine states in ^{87}Sr with intensity modulated laser light. [1]

Trapped neutral atoms have emerged as a rapidly progressing platform for quantum information processing. Alkaline-earth and alkaline-earth-like atoms are particularly attractive due to their long-lived qubit states, the theoretically well-understood hyperfine structure, and the ability to precisely control their interactions with external fields. Beyond qubits, the rich level structure of alkaline-earth atoms enables the use of multi-level qudits, which offer additional computational advantages, including increased information density and reduced circuit complexity.

We propose a fast and robust scheme for implementing single-qudit gates in alkaline-earth(-like) atoms operating in moderate to large magnetic fields. [1][2] The method relies solely on optical interactions, eliminating the need for oscillating magnetic fields. By optimizing the control parameters, we show that neighboring level flips on the order of several kilohertz can be driven with high fidelity via a single-beam Raman transition. Through a detailed analysis of the hyperfine structure of the $^1S_0 \rightarrow {}^3P_1$ optical transition, we identify the optimal magnetic field strengths and laser parameters required for universal single-qudit control. Numerical simulations demonstrate that this approach enables faster spin operations than current state-of-the-art techniques for manipulating atomic hyperfine qudits.

References

[1] J. K. Krondorfer, M. Diez, and A. W. Hauser, arXiv:2506.23143 [quant-ph] (2025)
[2] J. K. Krondorfer, S. Pucher, M. Diez, S. Blatt, and A. W. Hauser, arXiv:2501.11163 [quant-ph] (2025)

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