Entanglement of Four Particles

D. Kielpinski, V. Meyer, C.J. Myatt[1], C.A. Sackett, Q.A. Turchette[1],
W.M. Itano, C. Monroe, and D.J. Wineland

Time and Frequency Division, National Institute of Standards and Technology, Mailstop 847, 325 Broadway, Boulder CO 80303, USA
E-mail: davidk@boulder.nist.gov
[1] *Research Electro-Optics, 1855 S. 57th Ct., Boulder CO 80301, USA*

We demonstrate, for the first time, quantum-mechanical entanglement of four particles [1]. The particles are atomic beryllium ions confined in a linear RF trap. To produce entanglement, we implement the scheme of Mølmer and Sørensen [2], which uses a single laser pulse to create the maximally entangled state $(|\downarrow\downarrow\downarrow\downarrow\rangle + |\uparrow\uparrow\uparrow\uparrow\rangle)/\sqrt{2}$. Here the states $|\uparrow\rangle$ and $|\downarrow\rangle$ are hyperfine sublevels of the atomic ground state. This scheme involves a 4-photon transition that effectively flips all pairs of spins. The scheme is also scalable in principle, in that the same scheme will entangle any number of particles with a slowly-growing investment of resources. Using this method, we create approximately the desired state on demand, without needing to postselect our data. We characterize the experimentally created state and show that the four-particle density matrix is not separable in any basis that treats the ions as separate particles. Hence we produce an entangled state of the four particles deterministically in each shot of the experiment.

Acknowledgments. This research was supported by the NSA, ARO, and ONR.

[1] C.A. Sackett et al., Nature 404, 256 (2000).
[2] K. Mølmer & A. Sørensen, quant-ph/0002024; K. Mølmer & A. Sørensen, PRL 82, 1835 (1999).