# Quantum Optics Seminar

**Title:** QUANTUM GATES, ENTANGLEMENT, AND TELPORTATION

**Speaker:** Professor Ferdinand Schmidt-Kaler, Institut für Experimentalphysik, Universität Innsbruck

**Time:** Thursday, May 6, 2004, 10:15-11:00

**Place:** Aud. D3 at Department of Mathematical Sciences

**Abstract:**

Single ions and crystals of ions are confined in a linear Paul trap and are investigated for quantum information processing. Superpositions of the $S_{1/2}$ ground state and the long lived $D_{5/2}$ state are used to implement a qubit. The ions are optically cooled and fluorescence light at 397 nm on the $S_{1/2}$ - $P_{1/2}$ transition is monitored for a state measurement by the "electron shelving" technique. The $S_{1/2}$ - $D_{5/2}$ quadrupole transition at 729 nm is excited for cooling the crystals to the vibrational ground state and for the manipulation of individual qubits.

On a two ion crystal we have realized a *universal two-qubit quantum gate* [1]. The quantum state of the control qubit |c> determines the rotation of the quantum state of the target qubit |t> like |c>|t> → |c>|c ⊗ t>, where ⊗ indicates a modulo-2 addition. This gate operation is in principle fully scalable to larger strings of ions.

Second, we have deterministically generated all four *Bell states* $\Phi_{\pm}$=|SS> ± |DD>, and $\Psi_{\pm}$=|SD> ± |DS> with fidelity of 90% [2]. The density matrix of these Bell states has been fully determined by applying a quantum state tomography. We find that states of the type |SD±DS> exhibit ultra-long coherence times, reaching the fundamental limit of coherence which is given by the spontaneous decay of the upper qubit level at $\tau$=1s.

Using a three ion crystal we have generated *three ion entanglement*, namely the W-state |SDD> + |DSD> + |DDS> and the GHZ state |SDS> + |DSD>. The qubit entanglement is studied by determining the corresponding density matrices. Recently, we implemented deterministic, "on demand" *teleportation* with the elementary quantum processor.

References:

[1] F. Schmidt-Kaler, H. Häffner, M. Riebe, S. Gulde, G. P. T. Lancaster, T. Deuschle, C. Becher, C. F. Roos, J. Eschner & R. Blatt, Nature 422, 408-411 (2003).

[2] C. F. Roos, G. P. T. Lancaster, M. Riebe, H. Häffner, W. Hänsel, S. Gulde, C. Becher, J. Eschner, F. Schmidt-Kaler and R. Blatt, arXiv:quant-ph/0307210.

Michael Drewsen