Dissipation-assisted quantum computation with cold trapped ions

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Very recently, enormous progress has been made in quantum information processing with cold trapped ions. In Innsbruck, the Cirac-Zoller controlled-NOT quantum gate has been realised with the help of six concatenated laser pulses individually addressing each of the two ions [1]. At the same time, the group in Boulder experimentally demonstrated a robust, high fidelity geometric two ion-qubit phase gate. This was achieved with a sequence of laser pulses without individual addressing of the ions [2].

But are these schemes really suitable for quantum computation with many qubits? Finding reliable ways to scale present schemes to many qubits requires simplifications of the experimental setup while keeping the gate operation times short and increasing the robustness of each gate with respect to fluctuations of experimental parameters. Cooling techniques have to be improved and cooling of the ions should also be possible during gate operations.

In this paper we show that some of these problems can be overcame with the help of *dissipation-assisted adiabatic passages*. We present a simple scheme for the realisation of a two-qubit phase gate and SWAP operation between cold trapped ions that can be implemented by applying only single laser pulse [3]. The system remains always in a state with no phonons in the vibrational mode and the cooling lasers can be applied continuously.

In the proposed scheme, the effect of cooling of the ions is two-fold. It decreases the sensitivity of the setup to heating processes. At the same time, it allows to operate the scheme outside the adiabatic regime and to achieve gate operation times comparable to the one presented in [1] and [2]. The reason is that heating introduces an auxiliary dissipation channel into the system that damps away errors in case of non-adiabaticity. The presence of decay rates has the same effect as an error detection measurement and very high fidelities are obtained under the condition of no photon emission. Another advantage of the proposed scheme is that its performance does not depend on precise control of the atom-phonon coupling.

We also comment on the scaling of quantum computing schemes with fidelities above 99 % and success rates of each gate operation of the order of 90 %. Advantages compared deterministic schemes with finite error rates result from the fact that gate failure leads to the emission of photons at a high rate. This can easily be detected and the computation can be repeated if necessary.

[1] F. Schmidt-Kaler *et al.*, Nature **422** 408 (2003).
[2] D. Leibfried *et al.*, Nature **422**, 412 (2003).
[3] A. Beige, PRA **67**, 020301(R) (2003).