Accuracy of quantum logic operations with ion molecules

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We consider a new type of linear ion trap where a magnetic field gradient is applied along the axis of rotational symmetry of the trapping potential [1]. In such a trap the internal states (qubits) of different ions are coupled by an effective spin-spin interaction whose formal description is the same as that for J-coupling in molecules used for nuclear magnetic resonance (NMR) experiments [2, 3]. This coupling can be adjusted by choosing the trap parameters and the type of ion. Thus, an artificial ion "molecule can be designed where individual qubits are well isolated from their environment, can be individually addressed, and read out with nearly unity efficiency. Coherent manipulation of qubits is carried out using microwave instead of laser radiation. This will considerably reduce the experimental complexity, and, at the same time allow for long coherence times and precise realisation of quantum logic gates.

Theoretical studies of such ion molecules will be presented showing that schemes for conditional quantum dynamics with two qubits (e.g., a CNOT-gate) as used in NMR can be directly applied to ion molecules where some limitations to the accuracy of NMR methods are not present.

On the other hand, possible detrimental effects to quantum logic operations caused by unwanted terms in the Hamiltonian (due to the presence of the magnetic field gradient) describing the coupling between individual qubits of an ion molecule and the driving rf or microwave field are investigated. We explore the parameter space spanned by secular trap frequency, field gradient, and the number and temperature of ions in order to minimise unfavourable effects. In addition, possibilities to correct for inaccuracies of quantum logic operations due to these terms are discussed.

Further studies are concerned with the impact of anharmonic terms in the Coulomb potential governing the ions' relative motion on ion molecule quantum computing. The corrections that are found are either negligibly small or can be accounted for in the course of a quantum algorithm, if the trap parameters are suitably chosen. Subject of current studies is the effect of heating of the ions' motional degrees of freedom on the performance of quantum logic operations. The numerical studies to be presented consider as a specific example for ion molecule quantum computing $^{171}Yb^{+}$ ions where two hyperfine states of the electronic ground state serve as a qubit.

References

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