Qubit's state control and Entanglement transfer by large-S spin channels

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Creating and transferring entanglement are fundamental tasks when aiming at performing quantum operations. These tasks are usually accomplished using purely quantum channels, for instance spin-1/2 chains, which result very effective, but need a high level of protection against external disturbance. Moreover, when solid-state realizations of quantum devices are proposed, even addressing and manipulating single qubits without affecting the neighboring ones can be extremely difficult, since it most often requires the application of a highly localized time-dependent magnetic field. In fact, an ideal situation would be that of having a physical system, embodying a robust transmission line, capable of connecting one or several qubits to en external signal-source, and possibly of transferring entanglement from one qubit to another even if they are at distance.

Spin systems in one dimension (spin chains) with large-S ($S \gg 1$) seem to provide suitable candidates for embodying the required transmission line, since *i*)-they are interacting systems, extending along one spatial dimension; *ii*)-their dynamical behavior is well described by semi-classical equations, meaning they are not supposed to be sensitive to decoherence, and *iii*)-they posses classes of stable and localized dynamical configurations, namely solitons, which can be reasonably thought to be used as strong signals.

This thesis is devoted to the analysis of the different aspects concerning the use of a large-S spin chain as quantum information channel. We have first investigated a practical scheme to achieve the generation of soliton-like excitations on discrete classical Heisenberg chains by the application of a time-dependent magnetic field to one end of the system showing, by numerical techniques, the effective injection of solitons and their robustness against thermal disorder [1,2]. We have then proposed a setup where the generated soliton represents a magnetic signal travelling along the chain which eventually reaches a distant qubit in order to manipulate its quantum state. Numerical results confirm that solitons are indeed suitable for this task, giving the possibility to remotely control the qubit's state by an appropriate choice of soliton shape and qubit-chain coupling [1–4].

Since a full quantum description of a many-body large-S system interacting with some qubits is not feasible, we introduce a semi-classical approximation scheme based on single-spin coherent states; this scheme allows us to describe the dynamics of a system made by two distant (and not directly interacting) qubits and a large number of interacting spins, still retaining enough of the system's quantum nature to account for entanglement generation and transmission. In this way, considering a spin-S chain, we show that, choosing the chain initial state close to a localized classical dynamical configuration (soliton), the entanglement established between the first qubit and the chain can be transferred along the spin-S system through to the second qubit leading to an entangled state of the two distant qubits.

References

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