Abstract

Coherent dynamics of charge and spin excitations in one-dimensional systems

The control and design of the dynamics of quantum systems constitute the core of quantum information processing, and potentially it will enable new and improved applications of nanotechnology. In this context, some relevant examples are: Rabi's oscillations, design of quantum channels for quantum communication and control for the decay described by the Fermi golden rule. However, it is not clear how to obtain control on interacting spin systems. The high connectivity of the interactions and the complexity of the accessible states at room temperature go against this goal. In this thesis, we show how a controlled coherent dynamics can be obtained in interacting spin systems in Nuclear Magnetic Resonance (NMR) experiments. The key to obtain the desired degree of simplicity is the proper design of the effective interactions and the right choice of the coupling topology.

The fact that the nuclear spin interaction in a chain can be reduced into an XY (planar) interaction provides a first simplification. In this situation, the evolution of a local excitation is reduced to the dynamics in a non-interacting fermion system. We analyze a model that describes the decay of the polarization when the excited spin weakly interacts with a spin chain, that acts as its environment. This model allows us to study the coherent effects that the environment produces over the system. We consider the environment as non-Markovian, i.e., all the memory effects are taken into account. Then, we obtain a quantum and complete description of the decay of the local polarization. In particular, we found a novel interference effect in time domain, which we called survival collapse, which brings the local polarization down by several orders of magnitude. In this part, we study the exponential behavior of the decay and the non-exponential regime described by a power law. We interpret this last regime as a return probability of a quantum diffusive dynamics in the chain that acts as an environment.

In a second part of this thesis, we study how to obtain a simple dynamics taking advantage of the interactions that mix subspaces of different total spin projection. This strategy, called multiple quantum coherences, applied to a quasi-one-dimensional crystal has interest for the design of channels for quantum communication. In particular, we implemented NMR experiments in the solid state in hydroxyapatite; a polycrystalline sample susceptible to behave as a one-dimensional spin system. We observe that the coherent dynamics of the states of many interacting spins are manifested as an effective one-body dynamics, which confirms the potentiality as a quantum channel. We study the degradation of the coherence, i.e., the decoherence, through a temporal reversion procedure (Loschmidt echo), and we observe that the coherence is lost gradually, dominated by an exponential law, consistent with the low connectivity of the spin lattice.

Keywords: Quantum information, quantum communication, decoherence, quantum Zeno effect, nuclear magnetic resonance, spin echoes, quantum dynamics in magnetic resonance, exponential decay, non-Markovian environment, Fermi golden rule.

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