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FACOLTÀ DI SCIENZE MATEMATICHE, FISICHE E NATURALI.
Corso di Laurea Magistrale in Scienze Fisiche e Astrofisiche

Decoherence and measurement process as dynamical evolution of Open Quantum Systems

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In this work we study the dynamics of an Open Quantum System (OQS), i.e. a principal quantum system interacting with its likewise quantum environment.

We specifically address the type of evolution that leaves constant the diagonal matrix-elements of the principal system's density operator, named off-diagonal dynamics, which is responsible for fundamental processes such as decoherence. We show that the dynamical generation of entanglement between the principal system and its environment is a key issue in understanding the overall off-diagonal evolution; consequently, we adopt a recently introduced method for studying OQS that permits to fully retain the entanglement properties between principal system and environment. This method is based on an exact parametric representation of the former in terms of generalized coherent states for the latter, whose peculiar properties strongly mark the resulting approach (named Parametric Representation with Environmental Coherent States - PRECS). When focusing our attention on the decoherence process, besides providing a general description of the corresponding dynamics, the PRECS allows us to define a decoherence time, irrespective of the specific model considered. The analysis is applied to the interactions that induce decoherence in two paradigmatic OQS models, namely that of a qubit interacting with a bosonic- or spin-environment, and reveals that it is possible to get longer decoherence times not only by reducing the coupling with the environment, but also increasing the energy-scale that characterizes the environmental Hamiltonian, an effect that has been recently observed experimentally.

The emergence of the role played by the environment size in the above analysis leads us to exploit the special features that coherent states have as far as their classical limit is concerned. To this aim, we consider the formal relation between classical and large-N limits of quantum theories, as it emerges when introducing coherent states: such relation allows us, thanks to the specific formalism characterizing the PRECS, to describe the measurement process as the off-diagonal dynamics of an open quantum system whose environment is macroscopic. In fact, the resulting description suggests that a derivation of the wave function collapse postulate is possible.

The analysis of decoherence and measurement process obtained in this thesis, suggests that the same approach can be succesfully used for studying other relevant phenomena in the research area where the study of OQS gets close to the foundations of Quantum Mechanics.