General non-Markovian dynamics in open quantum systems

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The foundations of statistical mechanics are based on two fundamental yet unsolved problems: (i) how does macroscopic irreversibility emerge from microscopic reversibility? (ii) how does the system relax in general to thermal equilibrium with its environment? The answers to these questions rely on a deep understanding of the dynamics of systems interacting with their environments. Recent results on environment-induced quantum decoherence [1-4] enable us to address these problems. Decoherence is also a main concern in developing quantum information technology. The current understanding of decoherence dynamics has provided answers to several fundamental issues, such as quantum measurement and the quantum-to-classical transition. In the past two decades, many theoretical and experimental investigations were devoted to this topic, most of these taking the memory-less (Markov) limit. However, experimental implementations of nanoscale solid-state quantum information processing makes strong non-Markovian memory effects unavoidable, thus rendering their study a pressing and vital issue. By exploring non-Markovian processes, we find that decoherence manifests unexpected complexities. Indeed, an arbitrary given initial quantum state, under the influence of different reservoirs, can evolve into four different steady states: thermal, thermal-like, qumemory (= quantum memory) and oscillating qumemory. The first two de facto provided a rigorous proof how the system relaxes in general to thermal equilibrium with its environment. The latter two steady states, with strong non-Markovian effects, will maintain the initial state information and not reach thermal equilibrium, which is beyond the conventional wisdom of statistical mechanics. Applications to various nanostructures and micro- and nano-photonic systems are demonstrated [5-8].

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