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The theory of open quantum systems

The dynamical behavior of open quantum systems plays a key role in many applications of quantum mechanics, examples ranging from fundamental problems, such as the environment-induced decay of quantum coherence and relaxation in many-body systems, to applications in quantum optics, condensed matter theory, quantum transport, quantum chemistry and quantum information. In close analogy to a classical Markovian stochastic process, the interaction of an open quantum system with a noisy environment is often modelled phenomenologically by means of a dynamical semigroup with a corresponding time-independent generator in Lindblad form, which describes a memoryless dynamics of the open system typically leading to an irreversible loss of characteristic quantum features. However, in many applications open systems exhibit pronounced memory effects and a revival of genuine quantum properties such as quantum coherence, correlations and entanglement. We will discuss recent theoretical results on the rich non-Markovian quantum dynamics of open systems, paying particular attention to the rigorous mathematical definition, to the physical interpretation and classification, as well as to the quantification of quantum memory effects. We will further investigate various physical sources of non-Markovian quantum dynamics, such as structured environmental spectral densities, nonlocal correlations between environmental degrees of freedom and correlations in the initial system-environment state, in addition to developing experimental schemes for their local detection.