Quantum unitary evolution interspersed with repeated non-unitary interactions at random times: The method of stochastic Liouville equation

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We address the issue of what happens when the unitary evolution of a generic closed quantum system is interrupted at random times with non-unitary evolution due to interactions with either the external environment or a measuring apparatus. We adduce a general theoretical framework involving stochastic Liouville equation to obtain the average density operator of the system at any time during the dynamical evolution, which is applicable to any form of non-unitary interaction.

We first provide two explicit applications of the formalism in the context of the so-called tight-binding chain (TBC) relevant in various contexts in solid-state physics, for two representative forms of interactions: (i) stochastic resets, whereby the density operator is at random times reset to its initial form, and (ii) projective measurements at random times. For (i), we demonstrate with our exact results how the particle is localized on the sites at long times, leading to a time-independent mean-squared displacement of the particle about its initial location. For (ii), we show that repeated projection to the initial state of the particle results in an effective suppression of the temporal decay in the probability of the particle to be found on the initial state. The amount of suppression is comparable to the one in conventional Zeno effect scenarios, but which does not require to perform measurements at exactly regular intervals that are hallmarks of such scenarios.

For the case of the TBC subject to an external field periodic in time and being stochastically reset to the initial condition at exponentially-distributed random times, we derive using the aforementioned method of stochastic Liouville equation exact results for the probability at a given time for the particle to be found on different sites and averaged with respect to different realizations of the dynamics. We establish the remarkable effect of localization of the TBC particle on the sites of the underlying lattice at long times. The system in the absence of stochastic resets exhibits delocalization of the particle, whereby the particle does not have a time-independent probability distribution of being found on different sites even at long times, and, consequently, the mean-squared displacement of the particle about its initial loca- tion has an unbounded growth in time. One may induce localization in the bare model only through tuning the ratio of the strength to the frequency of the field to have a special value, namely, equal to one of the zeros of the zeroth order Bessel function of the first kind. We show that localization may be induced by a far simpler procedure of subjecting the system to stochastic resets.