Synchronizing spins in a collision model

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Abstract

We demonstrate the emergence of environment-induced spontaneous synchronization between two spin-1/2 quantum objects in a collision model setting. In particular, we determine the conditions for the establishment of synchronous dynamics between local spin observables of a pair of spins undergoing open-system dynamics in the absence of an external drive. Exploiting the versatility of the collision model framework, we clearly show that the accumulation of quantum or classical correlations between the principal spin pair are of no significant relevance to the manifestation of spontaneous quantum synchronization between them. Furthermore, we discuss the consequences of thermal effects on the environmental spins for the emergence of quantum synchronization.

Synchronization phenomenon manifests itself in various fields such as sociology, biology and physics [1]. One may follow its traces back to C. Huygens' observation of synchronous behavior of two coupled pendulum clocks in the 17th century. Besides this pioneering discovery, swinging metronomes, flashing fireflies, cardiac pacemakers and applauding audiences can be given as some examples of the systems tending to behave synchronous. In the forced synchronization, which is one of the two main classes of synchronous behavior, the system is driven by an external field acting as a pacemaker imposing its rhythm on the system. The spontaneous synchronization, on the other hand, shows up solely due to the coupling between subsystems in the absence of any external drive. Although the synchronization concept has been broadly investigated in the classical domain during the last few decades, its quantum mechanical counterpart has been taken into consideration recently [2,3].

Collision models have drawn considerable attention due to their versatility in modeling different regimes of the open quantum system dynamics, which is much harder to implement with other approaches [4]. In a collision model, the environment is formed by particles such that the system dynamics is governed by its sequential interaction with these environmental units. Along with the basic setting that yields a Markovian time evolution for the system, one can simply introduce intra-environment collisions to simulate a non-Markovian dynamics as well. Following the discussions on the memory effects and owing to their highly adoptable nature, quantum collision models have served as a test-bed for various ideas in several different fields, such as quantum thermodynamics, quantum optics, quantum control and recently their all-optical experimental implementation has been demonstrated [5].

We report here the occurrence of spontaneous mutual synchronization between two spin-1/2 particles in a collision model. Making use of Pearson's coefficient to quantify the temporal correlations between the local dynamics of two spins forming the open quantum system, we determine the physical conditions under which expectation values of local spin observables become synchronized in time. Specifically, we identify the requirements for the establishment of synchronized dynamical behavior between the spin observables depending on the parameters of the model, namely, detuning between the two system spins, strength of the coupling between them, and the interaction strength among the environmental spins. Moreover, owing to the versatility of collision models which enables full control over the dynamics of two open system spins, we investigate the role of correlations between the spins for their synchronous behavior in detail. Our findings clearly demonstrate the insignificance of the formation of correlations between the principal pair of spins for the emergence of spontaneous synchronization. Lastly, we study the consequences of having thermal effects on the environmental spins for the appearance of synchronization.

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