Breakdown of quantum-to-classical correspondence for diffusion in high temperature thermal environment

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The spreading of a particle along a chain, and its relaxation, are central themes in statistical and quantum mechanics. One wonders what are the consequences of the interplay between coherent and stochastic transitions. This fundamental puzzle has not been addressed in the literature, though closely related themes were in the focus of the Physics literature throughout the last century, highlighting quantum versions of Brownian motion. Most recently this question has surfaced again in the context of photo-synthesis.

In [1] we re-consider the old problem of Brownian motion in homogeneous high-temperature thermal environment. The semiclassical theory implies that the diffusion coefficient does not depend on whether the thermal fluctuations are correlated in space or disordered. We show that the corresponding quantum analysis exhibits a remarkable breakdown of quantum-to-classical correspondence. Explicit results are found for a tight binding model, within the framework of an Ohmic master equation, where we distinguish between on-site and on-bond dissipators. The breakdown is second-order in the inverse temperature, and therefore, on the quantitative side, involves an inherent ambiguity that is related to the Ohmic approximation scheme.

For quantum coherent dynamics one expects to observe ballistic motion and Bloch oscillations, while for classical stochastic dynamics one expects to see diffusion and drift. In [2] we have considered the puzzling case where coherent and stochastic transitions co-exist "in parallel". With added disorder it becomes the quantum version of the Sinai-Derrida-Hatano-Nelson model, which features sliding and the delocalization transitions. They highlighted non-monotonic dependence of the current on the bias, and a counter-intuitive enhancement of the effective disorder due to coherent hopping.

[1] Breakdown of quantum-to-classical correspondence for diffusion in high temperature thermal environment, D. Shapira, D. Cohen, Phys. Rev. Research 3, 013141 (2021).

[2] Quantum stochastic transport along chains, D. Shapira, D. Cohen, Sci. Rep. 10, 10353 (2020).