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Macroscopic particle transport in dissipative long-range bosonic systems

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The speed limit for macroscopic particle transport is one of the central topics in quantum mechanics, which quantifies the minimum time required for a given number of particles to propagate to a reachable regime. Recently, there are constant progress on maximal bosonic particle transport speed in Bose-Hubbard model and long-range bosonic models. However, the existing findings are limited to closed quantum systems. Due to intrinsic chemical reactions, coulping to the external environment and inelastic collisions between particles, these systems are usually not strictly closed and inevitably suffer from dissipation, such as dephasing and particle loss. The dissipation leads to the breakdown of traditional macroscopic particle transport theory. In this work, we determine the maximal speed of macroscopic particle transport in dissipative bosonic systems featuring both long-range hopping and long-range interactions. By developing a generalized optimal transport theory for open quantum systems, we rigorously establish the relationship between the minimum transport time and the source-target distance, and investigate the maximal transportable distance of bosons. We demonstrate that optimal transport exhibits a fundamental distinction depending on whether the system experiences one-body loss or multi-body loss. Furthermore, we present the minimal transport time and the maximal transport distance for systems with both gain and loss. We observe that even an arbitrarily small gain rate enables transport over long distances if the lattice gas is dilute. Moreover, we generally reveal that the emergence of decoherence-free subspaces facilitates the long-distance and perfect transport process. We also derive an upper bound for the probability of transporting a given number of particles during a fixed period with one-body loss. We also discuss ossible experimental protocols for observing our theoretical predictions.

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