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Evolution of entanglement entropy of strongly correlated bosons in an optical lattice

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Entanglement plays a crucial role in various quantum many-body phenomena, including the thermalization of isolated quantum systems and the information paradox of black holes. Notably, the second-order Rényi entropy (RE), a measure of entanglement, was successfully measured in the system of bosons in an optical lattice. Motivated by this experiment, we investigate the time evolution of the second-order RE of bosons in the one-dimensional optical lattice after a sudden quench of the hopping amplitude J. Specifically, we examine systems that are quenched into the strongly correlated Mott-insulating (MI) regime with $U/J \gg 1$ (U denotes the strength of the on-site repulsive interaction) from the MI limit with $J = 0$.

In this regime, the low-energy excited states are described by the effective theory of fermionic quasiparticles known as doublons and holons, which are excited in entangled pairs during the quench dynamics. By developing the effective theory, we derive the direct relation between the RE and correlation functions associated with doublons and holons. This connection enables us to analytically calculate the RE and to gain a physical understanding of its behavior, both in the ground state and in the time-evolved state after the quench, in terms of entangled doublon-holon pairs. In particular, we show that the RE is proportional to the population of doublon-holon pairs spanning the boundary of the subsystem.

Our quasiparticle picture reveals novel characteristics absent in previous studies on the dynamics of entanglement entropy in free-fermion models. It provides valuable insights into the behavior of entanglement entropy in strongly correlated systems.

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