Entanglement in fermionic systems

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Entanglement in systems of distinguishable components is particularly valuable in the field of quantum information theory because it can be considered as a resource within the Local Operations and Classical Communica-tion (LOCC) paradigm. Extending the notion of entanglement to the realm of indistinguishable particles is, however, not straightforward because the constituents of the system cannot be individually accessed.

Different approaches have been considered, like mode entanglement, where subsystems correspond to a set of single particle (SP) states in a given basis, extensions based on correlations between observables and entanglement beyond symmetrization [1,2], which is independent of the choice of SP basis. Several studies on the relation between these types of entanglement and on whether exchange correlations can be associated with entanglement [3] have been made. This work focuses on entanglement beyond antisymmetrization. We examine fermionic entanglement measures [2] in the exact ground state of strongly interacting systems such as a superconductor [4] and a Lipkin system [5].

It is shown that global measures such as the one-body entanglement entropy, exhibit a close correlation with the relevant mean field (MF) order parameters, i.e. the BCS gap and hence pairing in a superconducting system [4], saturating in the strong coupling regime [4,5]. In contrast, the entanglement of the reduced state of four single-particle modes, which can be measured through the fermionic concurrence [1,2], is peaked at the fundamental GS phase transition [4,5], for states close to the Fermi level, becoming small for strong couplings. While the first measures can be estimated through MF approaches, the concurrence lies strictly beyond the latter, requiring either symmetry-restoration or RPA correlations for its correct description [4,5]. Ground state fermionic separability [5] is also discussed. These studies are framed in the development of a completely fermionic resource theory [6].

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