Quantized Berry Phases and Entanglement Entropy in Quantum Liquids: For a Characterization of Topological Orders

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In strongly correlated electron systems in low dimensions, quantum fluctuation prevents from a formation of local order even at a zero temperature. Such a state can be understood as a quantum liquid where the standard symmetry breaking does not play any fundamental role. Typical examples are resonating valence bond (RVB) states by Anderson and Pauling, where basic components of the states are not spins (as small magnets) neither localized electrons (as local charges) but local singlet pairs and covalent bonds respectively (Fig.). Both of them are local and simple but purely quantum objects, which do not have classical correspondences. This is the reason the classical symmetry breaking is useless here. Then we propose to characterize these quantum objects by quantized Berry phases as topological local order parameters for generic quantum liquids [1]. Generically the Berry phase takes any value but has to be quantized for anti-unitary invariant states such as time-reversal (Fig.(a):Anderson) or particle-hole (Fig.(b):Pauling) invariant ones. The scheme can be useful for various quantum liquids. Typical targets can be Heisenberg spin systems with frustrations and dimerized fermions, where the validity is verified [1]. This is a local characterization.

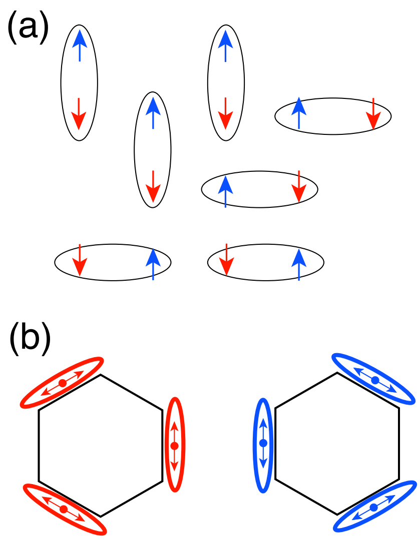

Fig. Schematic pictures of the RVB states by Anderson (a) and Pauling (b). Many body quantum states are composed of superposition of local singlet pairs and covalent bonds.

Further as for a global characterization of the quantum liquids, a novel quantity such as entanglement entropy originally discussed in the quantum information can be quite useful. We have constructed a general formulation and demonstrated the validities for several fermionic systems [2].

[1] Y. Hatsugai, cond-mat/0603230, cond-mat/0607024.

[2] S. Ryu and Y. Hatsugai, Phys. Rev. B73, 245115 (2006)