Study on frustrated quantum spin systems using machine-learning solvers

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Frustrated spin systems may host spin liquid ground states. Once the spin liquid states are realized, we can expect several intriguing behaviors such as fractionalized excitation. Therefore, possibility of realizing spin liquid states is investigated intensively from both experiment and theory.

One of the candidate Hamiltonians for realizing spin liquid is J_1-J_2 Heisenberg model on the two-dimensional square lattice, where the next nearest neighbor exchange J_2 competes with the nearest neighbor exchange J_1, with geometrical frustration. Despite much numerical effort, the controversy on the ground state of the square-lattice J_1-J_2 Heisenberg model has not been settled yet.

In the present study, we introduce very accurate variational wave functions utilizing machine learning techniques to investigate the ground state of J_1-J_2 Heisenberg model. The variational wave function is constructed by combining the restricted Boltzmann machine (RBM) and the pair-product (PP) states. The RBM is a type of artificial neural networks, allowing for a flexible and unbiased description of a wide variety of quantum states [1]. The PP wave function or geminal wave function used in conventional wave-function methods properly describes nonlocal entanglement, helping machine learning to learn many-body ground states efficiently. The combined wave function has been shown to give highly accurate results [2].

Using the accurate RBM+PP wave function, we investigate the possible spin liquid in the J_1-J_2 Heisenberg model. In particular, we focus on the correlation ratio and level crossing. The correlation ratio is based on the ratio between the peak value of structure factor in the momentum space and the value at the neighboring momentum, and is a very sensitive probe for the phase transition [3]. The level crossing of the excited states is also useful in detecting the phase transition [4]. Our numerical results of the correlation ratio and level crossing both suggest a spin liquid ground state for a finite range of J_2 around $J_2/J_1= 0.5$. The spin liquid in this model is shown to be gapless, in which both the singlet and triplet sectors become gapless.

References

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