Tensor-Network Representation of Gapless Kitaev Spin Liquids[1]

Naoki KAWASHIMA
Institute for Solid State Physics, University of Tokyo
Kashiwa-no-ha, Kashiwa, Chiba 277-8581

While the tensor network (TN) representation is recently used as the variational ansatz for various quantum many-body problems, it is also useful in capturing essence of novel quantum states, with the AKLT state as a well-known example. The Kitaev honeycomb model (KHM) is an exactly soluble model which exhibits gapless and gapped KSL ground states with fractionalized excitations. Recent successful realizations of Kitaev materials triggered a burst of theoretical investigations on it. In the present work, we propose a compact TN representation for KHM. Our variational wave function has the form $|\psi_n\rangle \equiv P_{\mathrm{LG}} R_{\mathrm{DG}}(\phi_n) R_{\mathrm{DG}}(\phi_{n-1}) \cdots R_{\mathrm{DG}}(\phi_1)|(111)\rangle$ where $|(111)\rangle$ is the state where all spins are aligned to the (111) direction. The two operators P_{LG} and R_{DG} are essential in constructing the series of ansatze. The first one, P_{LG}, is the 'loop-gas operator', which is defined as the sum of all TN operators (TPOs), each corresponding to a loop gas configuration. The second operator $R_{\mathrm{DG}}(\phi)$ is defined in a similar fashion, i.e., the sum of all TPOs corresponding to dimer-gas configurations. The parameter ϕ is such that $\tan\phi$ is the fugasity of the dimers.

The zero-th order ansatz ϕ_0, which is just a 'loop-gas state',

$|\psi_0\rangle =$  $+ \cdots$

It has a remarkable feature that it is exactly identical to the classical loop-gas model. Therefore, without numerical calculation, we can say that it belongs to the Ising universality class. By optimizing $|\psi_1\rangle$, we can achieve much more accurate estimate (0.2% relative error in energy). Since the state is not exactly solvable any more, we must verify its critical properties. Our calculation shows, with more than 2 digit accuracy, that ψ_1 have the same critical properties regardless of the value of ϕ_1. Going to the even higher order approximation, ϕ_2, we can obtain very accurate result (0.007% error). From these results, we strongly believe

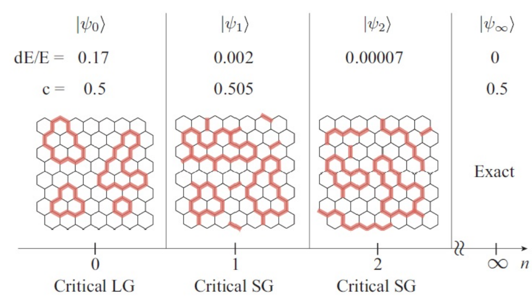

Figure 1: Comparison among the k-th order ansatze. While all belong to the same universality class, the energy converges quickly to the exact ground state energy of KHM.

that the present series of ansatze quickly converge to the exact ground state of the KHM (Fig.1), while retaining the essential properties of the KHM from the beginning ϕ_0.

[1] This report is based on H.-Y. Lee (ISSP), R. Kaneko (ISSP), T. Okubo (U. Tokyo) and N. Kawashima (ISSP), arXiv:1901.05786