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Random singlets and permutation symmetry in the disordered spin-2 Heisenberg chain: A tensor network renormalization group study

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We study random \(S = 2 \) antiferromagnetic Heisenberg chains with alternating bond strengths using the tensor network renormalization group method. In the clean limit,\cite{Damle2002} dimerization induces two quantum critical points separating three valence bond solid (VBS) phases: \((\sigma, 4 - \sigma) = (2,2), (3,1), (4,0) \), characterized by \(\sigma \) valence bonds on even links and \(4 - \sigma \) on odd links. Introducing bond randomness, we compute disorder-averaged twist order parameters and spin correlations to classify the resulting random VBS phases. The twist order parameter changes sign with \(\sigma \)'s parity, distinguishing between even and odd VBS phases. Our results reveal a multicritical point at intermediate disorder and finite dimerization, where the three VBS phases converge. This point lies at the junction of three phase boundaries in the \(R\text{-}D \) plane. In the undimerized limit (\(D = 0 \)), the multicritical point separates a gapless Haldane phase from an infinite-randomness critical line. We further identify the (3,1)-(4,0) boundary as an infinite-randomness line even at weak disorder, and observe similar behavior near the (2,2)-(3,1) boundary close to the multicritical point.

Primary author: LIN, yentung

Presenter: LIN, yentung

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