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Symmetry, topology, duality, chirality, and criticality in a spin-1/2 XXZ ladder with a four-spin interaction

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We study the ground-state phase diagram of a spin-$\frac{1}{2}$ XXZ model with a chirality-chirality interaction (CCI) on a two-leg ladder. This model offers a minimal setup to study an interplay between spin and chirality degrees of freedom. The spin-chirality duality transformation allows us to relate the regimes of weak and strong CCIs. By applying the Abelian bosonization and the duality, we obtain a rich phase diagram that contains distinct gapped featureless and ordered phases. In particular, Néel and vector chiral orders appear for easy-axis anisotropy, while two distinct symmetry protected topological (SPT) phases appear for easy-plane anisotropy. The two SPT phases can be viewed as twisted variants of the Haldane phase. We also present an effective description in terms of (spinor) hard-core bosons, which reveals critical behavior on the self-dual line in the easy-axis and easy-plane regimes. We perform numerical simulations to confirm the predicted phase structure and critical properties. We further demonstrate that the two SPT phases and a trivial phase are distinguished by topological indices in the presence of certain symmetries. A similar phase structure is expected in a spin-$\frac{1}{2}$ XXZ ladder with four-spin ring exchange.

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