Spin-Chirality Interplay in an XXZ Ladder with Four-Spin Interaction: Duality and Topology

January 2025

FONTAINE, Mateo Olivier Jean-Marie Michel

Thesis Abstract

No.

Registration Number	☑ "KOU" □ "OTSU" No. *Office use only	Name	FONTAINE, Mateo Olivier Jean-Marie Michel

Thesis Title

Spin-Chirality Interplay in an XXZ Ladder with Four-Spin Interaction: Duality and Topology

Thesis Summary

I investigated the ground-state phase diagram of a spin-1/2 XXZ model with chirality-chirality interaction (CCI) on a two-leg ladder, considering both isotropic and weakly anisotropic cases. This model provides a minimal setup to explore the interplay between spin and chirality degrees of freedom and is potentially relevant for understanding the effects of four-spin ring exchange. Additionally, anisotropic interactions enable the emergence of various orders and symmetry-protected topological (SPT) phases on the ladder.

Spin-chirality duality transformations allowed me to relate the regimes of weak and strong CCIs. By applying Abelian bosonization in combination with two types of spin-chirality dualities, I derived a comprehensive phase diagram. Furthermore, I developed a spin-1 hard-core bosons approach to analyze the phase structure around the self-dual line in the presence of strong anisotropy. I have also performed numerical simulations to validate the predicted phase diagrams and to examine the topological and critical properties.

In the isotropic (Heisenberg) model with CCI, the phase diagram consists of the rung singlet (RS) phase, the Haldane phase, dimer phases, and a scalar chiral phase. Within the RS and Haldane phases, I identified eight distinct regions with dominant correlations in terms of spin, dimer, or chirality. In particular, the dominance of staggered and uniform vector chiral (VC) correlations in the RS phase for strong positive and negative CCIs can be interpreted as dual counterparts to the conventional Néel correlation.

The introduction of weak XXZ anisotropy further enriches the phase structure within the region of positive CCI and antiferromagnetic rung interaction. Specifically, Néel and VC orders emerge for easy-axis anisotropy, while two distinct SPT phases emerge for easy-plane anisotropy. For strong anisotropy, a direct Gaussian transition occurs between Néel and VC or between the two SPT phases. Although both SPT phases can be viewed as twisted variants of the Haldane phase, I showed that they, along with the RS phase, can be distinguished by topological indices in the presence of specific symmetries.

In these ways, I demonstrated that the combination of anisotropy and multi-spin interactions generates rich and diverse physics characterized by chirality and topology.