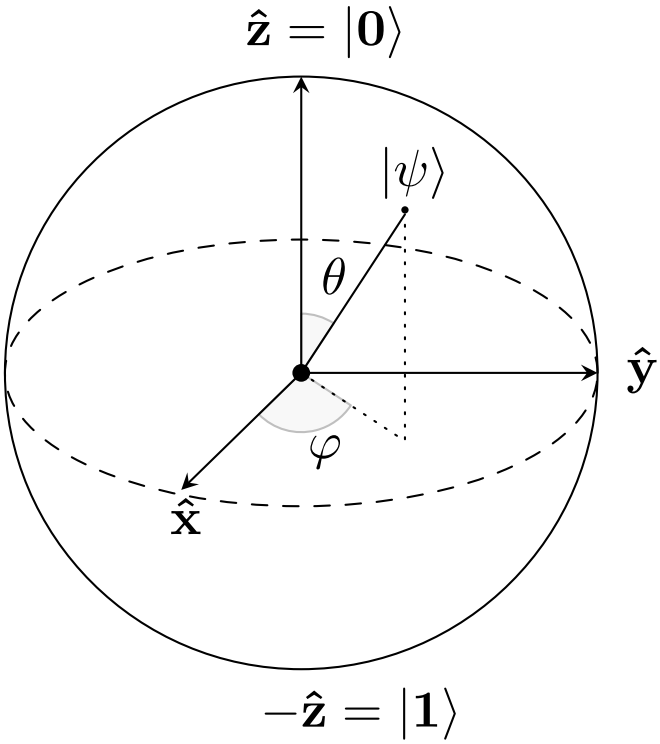
Report intership - 4A
Polytech Clermont-Ferrand - GP4A (2023 - 2024)
Engineering Physics Department

Entanglement in a spin chain



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Abstract

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Quantum information XY-Γ chain

Keywords :

Acknowledgements

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Glossaries

1. Introduction

1.1 Model XY − Γ

The XY-Γ model is an extension of the one-dimensional XY spin-1/2 model, incorporating an additional symmetric off-diagonal interaction term denoted by Γ. The Hamiltonian of this model is given by:

$$\hat{\mathcal{H}} = \hat{\mathcal{H}}_{XY} + \hat{\mathcal{H}}_{\Gamma}, \tag{1}$$

where

$$\hat{\mathcal{H}}_{XY} = J \sum_{n=1}^{L} \left[\left(\frac{1+\delta}{2} \right) \sigma_n^x \sigma_{n+1}^x + \left(\frac{1-\delta}{2} \right) \sigma_n^y \sigma_{n+1}^y \right] + h \sum_{n=1}^{L} \sigma_n^z, \tag{2}$$

and

$$\hat{\mathcal{H}}_{\Gamma} = \Gamma \sum_{n=1}^{L} \left(\sigma_n^x \sigma_{n+1}^y + \gamma \sigma_n^y \sigma_{n+1}^x \right). \tag{3}$$

Here, $\sigma^x, \sigma^y, \sigma^z$ are the Pauli matrices, J is the exchange constants, δ is the anisotropy parameter, h is the strength of the transverse field, and Γ characterizes the amplitude of the off-diagonal exchange interactions with γ being the relative coefficient of these couplings.

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1.2 Physical Interpretation

1.2.1 Interactions and Terms

- **XY term** : $\hat{\mathrm{H}}_{XY}$ describes the nearest-neighbor interactions along the x and y directions with anisotropy δ and a transverse magnetic field h.
- Γ **term or Dzyaloshinskii-Moriya interaction** : $\hat{\mathrm{H}}_{\Gamma}$ introduces an additional interaction that mixes the x and y components of neighboring spins, breaking mirror symmetry (Because the particle at position n does not have the same orientation of spin as the particle at position $n+1$, as represented by the term $\sigma_n^x \sigma_{n+1}^y$, where the particle at position n has a spin oriented in the x direction and the particle at position $n+1$ has a spin oriented in the y direction.).

1.2.2 Magnetocrystalline anisotropy

Explaintion of the anisotropy term δ :

Magnetocrystalline anisotropy arises from the crystalline structure of a material, influencing the preferred direction of magnetization. This direction varies based on the material's lattice structure; for example, iron with a cubic lattice favors the ±xyz directions, while nickel prefers diagonal directions. The phenomenon is attributed to differing interaction strengths

between neighboring lattice sites along various crystal planes. In polycrystalline films, composed of randomly oriented small clusters, the average magnetocrystalline anisotropy is negligible. Similarly, in amorphous films, where inter-atomic distances are random, this anisotropy can also be ignored.

Paper : Magnetic Anisotropy Assistant: Yifan Zhou, +358-451345822

1.2.3 Phases of the Model

- **Ferromagnetic (FM) Phase**: Characterized by aligned spins, typically occurring at low transverse field strength h.
- **Paramagnetic (PM) Phase**: Spins are disordered due to a strong transverse field.
- **Spiral Phase**: Exhibits a quasi-long-range order, with spins forming a spiral pattern. This phase emerges due to the interplay between the XY interactions and the Γ term.

1.3 Information Propagation

- The Γ interaction affects the way information spreads through the system. It creates an asymmetric "light-cone" structure with different propagation speeds (butterfly velocities) for information in different directions.
- In the spiral phase, information propagates faster compared to the FM and PM phases, where the propagation is slower.

1.4 Applications

cf Paper Simulation of XY model in a quantum computer Author: Marc Farreras Bartra

Paper ()

2. Methodology

Methodology

- Numerical approch
- Algo : Solve Schrodinger EQUATION
- Algo : Found Concurrence
- Analytical approch
- (cf intro report for Guillermo)

3. Results And Discussion

Results And Discussion