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Spin current in quantum XXZ spin chain

Junpeng Cao [a,*], Yupeng Wang [a,b]

[a] *Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100080, People's Republic of China*
[b] *International Center for Quantum Structures, Chinese Academy of Sciences, Beijing 100080, People's Republic of China*

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Abstract

The spin current in the one-dimensional quantum XXZ spin chain is studied based on the exact solutions. It is found that the spin voltage controlled by the unparallel boundary magnetic fields can induce the pure longitudinal spin current in the system. By using Wiener–Hopf and generalized algebraic Bethe ansatz methods, the analytic expressions for the spin current and the spin conductance are obtained. The spin current is proportional to the inverse of the length of the spin chain. The magnitude of spin current can be manipulated by the strength and the twist angle of two boundary magnetic fields. The exact analysis also shows that there exist an Ohm law or London equation type relation between the spin current and the spin conductance.

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Keywords: XXZ spin chain; Spin current; Bethe ansatz

1. Introduction

Many experimental and theoretical efforts have been put on the controlling of spin degree of freedom in recent years [1–3]. Spin-dependent effects, such as giant or colossal magnetoresistance and magnetization switching, arise from the interactions between spin of carrier and applied external magnetic fields. In the field of spintronics, instead of charge, electron spin carries information, and it is possible that capability and performance can be enhanced in spin-

* Corresponding author.
E-mail address: junpengcao@aphy.iphy.ac.cn (J. Cao).

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tronics devices. Possible applications and fundamental sciences involved make the study of spin-dependent transport an intensive field in condensed matter physics. Apart from the spintronics with a dilute doping of manganites in semiconductors [3] and the spin Hall effects emerging from the spin–orbital coupling in two dimensions [4–7], the spin transport properties caused by the quantum fluctuations from different spin magnitudes as well as many-body interactions in the one-dimensional (1D) Heisenberg systems are also great of interest. For instance, ballistic transport characterized by finite Drude weight or spin stiffness at finite temperature has been studied in some integrable systems [8] and some classes of Luttinger liquids [9]. Experimentally, mean free paths of several hundred nanometers were found to indicate a quasi-ballistic transport of quasi-particles in some samples, such as Sr_2CuO_3 and $SrCuO_2$.

Several ways to produce a pure spin current are proposed, such as anomalous Hall effect in ferromagnetic metals [10,11], ferromagnetic resonance [12,13], and the spin current in a spin spiral state [14,15]. In a recent work, Meier and Loss studied the magnetization transport properties in a finite spin-half Heisenberg chain linked to two bulk magnets [16]. They obtained a finite spin conductivity for a confined antiferromagnetic chain and predicted that a magnetization current may produce an electric field. Schütz, Kollar and Kopietz investigated a mesoscopic spin ring in the inhomogeneous magnetic field to search for persistent spin current with different exchange interactions or spin magnitudes [17]. Mal'shukov, Tang, Chu and Chao proposed a experimental proposal to show that the spin current can induce a spin torque due to the spin–orbit couplings, while a semiconductor–metal interface and a insulating substrate are needed [18].

In this paper, we show that the spin voltage or the spin torque controlled by the unparallel boundary magnetic fields can induce the spin current in the 1D quantum XXZ spin chain. We apply two unparallel boundary magnetic fields to the system to generate the spin voltage. Fortunately, by carefully choosing the boundary conditions, the system can be solved exactly. Thus our results are based on the exact solutions. The exactly solvable spin model is a very good tool to study the spin systems and provides a powerful starting point to understand the spin-dependent phenomena. Our strategy is as following. By synthetical using of the gauge transformations, the generalized algebraic Bethe ansatz [19,20] and the Wiener–Hopf methods [21], we obtain the analytic expressions for the spin current and the spin conductance at the ground state. We find that the spin current is proportional to the inverse of the length of the spin chain. The magnitude of spin polarized current can be tuned by the strength and the twist angle of two boundary magnetic fields. The spin current and the spin conductance satisfy a beautiful and simple analytic formula.

The paper is organized as follows. In Section 2, we construct a 1D quantum XXZ spin chain with unparallel boundary magnetic fields. In Section 3, we derive the exact solutions of the system by using the generalized quantum inverse scattering method. The thermodynamics of the system is given in Section 4. The ground state is discussed in Section 5. In Section 6, we derive the explicit analytic formulas for the spin current and the spin conductance. Section 7 contains some conclusions and discussions.

2. The model

We consider a generalized 1D anisotropic XXZ Heisenberg model with unparallel boundary magnetic fields, where the boundary magnetic fields are constrained lying in the xy plane. The model Hamiltonian reads