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Deformations of the spin currents by topological screw dislocation and cosmic dispiration

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ABSTRACT

We study the spin currents induced by topological screw dislocation and cosmic dispiration. By using the extended Drude model, we find that the spin dependent forces are modified by the nontrivial geometry. For the topological screw dislocation, only the direction of spin current is bent by deforming the spin polarization vector. In contrast, the force induced by cosmic dispiration could affect both the direction and magnitude of the spin current. As a consequence, the spin-Hall conductivity does not receive corrections from screw dislocation.

1. Introduction

Topological defects are predicted in most of the unified theories of fundamental force. In last few decades, this subject has drawn special attention in several areas of physics ranging from condensed matter physics to cosmology [1–42]. The topological defects could be formed at phase transitions in the early history of the universe, such as the cosmic string [27–30], the domain wall [30–32,34–36], and the global monopole [38]. In particular, the cosmic string theory provides a bridge between the physical descriptions of microscopic and macroscopic scales, and then leads to extensive discussions on various quantum problems. The influences of topological defects on the Landau levels have been investigated in Refs. [37,20]. It was shown that the presence of a cosmic string breaks the infinite

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degeneracy of the Landau levels. Reference [21] investigated the Landau quantization for a neutral particle with permanent magnetic dipole moment in the spacetime backgrounds of cosmic string and cosmic dislocation. And more recently, the relativistic and non-relativistic quantum dynamics of a neutral particle with both permanent magnetic and electric dipole moments were studied in the curved spacetime [22]. The topological Aharonov–Bohm and Aharonov–Casher effects have also been studied in the presence of a topological defect [24,23]. Then influences on the spin-hall effects have also been studied [6–13]. Usually the nontrivial geometries could modify the spin–orbital interaction, which is the focus of this paper.

The study of spin–orbit interactions received strong attention at ever-increasing speed since it is the theoretical foundation of the spin Hall effect (SHE) or spintronics [43] which studies the flow of the electron spin in the band structure of solid. The SHE was predicted in first by M.I. Dyakonov and V.I. Perel in 1971 [44,45]. This effect, which occurs as a result of the spin–orbit coupling (SOC) between electrons and impurities, is called extrinsic [46]. Conversely, intrinsic mechanism also exists [47–50]. It is caused by spin–orbit coupling in the band structure of the semiconductor, and then survives in the limit of zero disorder. Study of the intrinsic SHE has become an active field of research in recent years [51–56]. In general, the spin current is not conserved because of the exchange of angular momentum between electron and acting electromagnetic fields through the spin–orbital interaction. Matsuo et al. [57] discussed the angular momentum exchange between electron and mechanical angular momentum of the condensed matter system, and claimed that mechanical manipulation of spin currents is possible. In Ref. [7], SHE on noncommutative space was investigated for the first time by using the extended Drude model [50], and showed that on noncommutative space, this is a preferable direction for spin flow, and deformed accumulations of spin states on the edges of sample will occur. Based on a semiclassical approach to noncommutative quantum mechanics, SHE has also been discussed in Ref. [58]. In this paper, we discuss the influences of a screw dislocation and a massive dispiration [14,15] on the spin currents based on the extended Drude model.

The contents of this paper are organized as follows: in Section 2, we review the spin dynamics in the curved spacetime which has been studied in our previous paper [6]. In Section 3, we discuss the effects of the screw dislocation on the spin current and spin-Hall conductivity. It turns out that only the direction of the spin current is modified via the deformation of the polarization vector. In Section 4, we discuss the effects of the cosmic dispiration on the spin current and spin-Hall conductivity. In this case both the direction and magnitude of the spin current receive corrections. The conclusions are given in final Section 5.

2. Spin dynamics in curved spacetime

In this section, we review the dynamics of spin-1/2 particle in the electromagnetic fields in the curved spacetime [6]. In this case the Dirac equation is extended into the general covariant form [25],

$$[\tilde{\gamma}^{\mu}(x)(p_{\mu} - qA_{\mu}(x) - \Gamma_{\mu}(x)) + mc^2]\psi(x) = 0, \qquad (1)$$

where A_μ is the electromagnetic gauge potential, $\Gamma_\mu(x)$ is the spinor connection, and $\tilde{\gamma}^{\mu}(x)$ are the elements of coordinate dependent Clifford algebra in the curved spacetime and satisfy the relation $\{\tilde{\gamma}^{\mu}(x), \tilde{\gamma}^{\nu}(x)\} = 2g^{\mu\nu}(x)$, here $g^{\mu\nu}(x)$ is the metric of the spacetime in the presence of topological defect. The line element for a general spacetime is given by

$$\mathrm{d}s^2 = g_{\mu\nu}(x)\mathrm{d}x^{\mu}\mathrm{d}x^{\nu}. \qquad (2)$$

In the formalism of vierbein (or tetrad), which allows us to define the spinors in curved spacetime, the metric has the form [25],

$$g_{\mu\nu}(x) = e^{a}_{\ \mu}(x)e^{b}_{\ \nu}(x)\eta_{ab}, \qquad (3)$$

and the inverse vierbein can be defined by the relations $e^{a}_{\ \mu}e^{\mu}_{\ b} = \delta^{a}_{\ b}$ and $e^{\mu}_{\ a}e^{a}_{\ \nu} = \delta^{\mu}_{\ \nu}$. The spinor connection Γ^{μ} is connected to the vierbein with the relation

$$\Gamma^{\mu} = \frac{1}{8}\omega_{\mu ab}(x)[\gamma^{a}, \gamma^{b}] = \frac{1}{8}e_{a\nu}\nabla_{\mu}e^{\nu}_{\ b}[\gamma^{a}, \gamma^{b}]. \qquad (4)$$