行政院國家科學委員會專題研究計畫　成果報告

低維系統中的磁性及傳輸性質之研究

計畫類別：個別型計畫
計畫編號：NSC93-2112-M-029-006-
執行期間：93 年 08 月 01 日至 94 年 07 月 31 日
執行單位：東海大學物理學系

計畫主持人：楊明峰

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中　華　民　國 94 年 10 月 31 日

行政院國家科學委員會補助專題研究計畫成果報告

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※ 低維系統中的磁性及傳輸性質之研究 ※

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計畫類別：■個別型計畫　　□整合型計畫

計畫編號：NSC　93－2112－M－029－006－

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執行單位：東海大學物理系

中　華　民　國　　94 年　　10 月　　31 日

行政院國家科學委員會專題研究計畫成果報告
低維系統中的磁性及傳輸性質之研究
Study on the magnetic and transport properties in low-dimensional systems

計畫編號：NSC 93－2112－M－029－006－
執行期限：93 年 8 月 1 日至 94 年 7 月 31 日
主持人：楊明峰　　執行機構及單位名稱：東海大學物理系
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一、中文摘要

我們利用半古典的方法來研究亞鐵磁性的介觀自旋環在一個非均勻的外加磁場下，其永久磁化流的性質。我們發現，即便在絕對零度下而使得其自旋子的數目為零，它的永久磁化流仍不為零。此外，其永久磁化流在低溫下會隨溫度呈指數變化；而在更高的溫度下，則隨溫度成正比關係。

關鍵詞：介觀自旋環，永久磁化流

Abstract

Using a semiclassical approach, we study the persistent magnetization current of a mesoscopic ferrimagnetic ring in a nonuniform magnetic field. At zero temperature, there exists persistent spin current because of the quantum fluctuation of magnons, similar to the case of an antiferromagnetic spin ring. At low temperature, the current shows activation behavior because of the field-induced gap. At higher temperature, the magnitude of the spin current is proportional to temperature, similar to the reported result of a ferromagnetic spin ring.

Keywords: mesoscopic spin ring, persistent magnetization current

二、緣由與目的、結果與討論

Persistent charge current in a mesoscopic metal ring was predicted [1] and observed [2] a decade ago. In such a ring threaded by a magnetic flux, if the phase coherence length of electrons is larger than the size of the ring, then the electrons can pick up an Aharonov-Bohm phase after circling the ring once. Such a phase lag (or advance) would lead to a persistent current, which is a periodic function of the threaded magnetic flux [3], and can be detected via the magnetic response of the (isolated) ring. The phase lag (or advance) can also be of geometric origin (Berry phase) [4]. It has been proposed that a Berry phase can appear for an electron moving around the metal ring that subject to a textured magnetic field (or magnetization) [5]. This geometric phase, which depends upon the solid angle associated with the textured magnetic field, can lead to persistent charge and spin currents [5]. A similar geometric phase appears due to the spin-orbit interaction in one-dimensional rings [6,7], which is a manifestation of the Aharonov-Casher effect [8]. More studies on the persistent current related to the AC effect can be found in Refs. [9-11].

With the advance of spintronics and quantum computation [12], it becomes more important to understand the behavior of the spin current. Among these investigations, spin transport in pure spin systems plays a special role since there is no complication from charge degrees of freedom. In a recent paper, using a semiclassical spin wave analysis, Schütz *et al*. predicted the existence of persistent spin current in a mesoscopic ferromagnetic (FM) spin ring in a *nonuniform* magnetic field [13]. The FM spin ring being considered is a charge insulator with Heisenberg spin interaction, and the spin current is carried by magnon excitations. Similar to the case of charge transport in a metal ring subject to a textured magnetic field [5], the magnon in a mesoscopic FM spin ring acquires a geometric phase from the (nonuniform) spin texture of the classical ground state. The persistent current is found to be zero at temperature $T = 0$, and proportional to T when $k_B T$ is larger than the field-induced energy gap of the magnons.

Similar method has been applied to an antiferromagnetic (AFM) spin ring with a Haldane gap [14]. As compared with the FM case, there are some subtleties in using the semiclassical method in the AFM case. Due to the problem of infrared-diverging magnetization, the spin-wave approach is not valid for AFM spin chains with half-integer spins [14]. That is the reason why only the integer-spin cases are considered in Ref. [14]. Nonetheless, in the integer-spin case, an additional staggered field in the direction of the classical magnetization vectors still has to be introduced. Its value needs to be determined self-consistently before quantitative predictions can be made. The authors of Ref. [14] find that, unlike the case of the FM spin ring, the persistent spin current in an AFM spin ring can be nonzero at $T = 0$ due to quantum fluctuations. When the spin correlation length is much longer than the size of the ring, the magnitude of the spin current exhibits sawtooth variation with respect to the geometric phase, similar to the case of persistent charge current in a metal ring. Recently, the investigation has been extended to an anisotropic FM spin ring [15], a spin-1/2 AFM spin ring [16,17], and an anisotropic AFM spin ring [18].

In this work, we study the persistent spin current in a ferrimagnetic (FIM) spin ring with alternating spins S^A and S^B under a textured magnetic field. Contrary to the AFM case, the problem of infrared-diverging magnetization does not exist in the present FIM case, no matter whether the constituent spins are integer or half-integer [19-22]. Thus the self-consistently determined staggered field needs not be introduced, and physical quantities can be calculated directly as long as system parameters are known. We find that the FIM spin ring can have either FM or AFM characteristics. For example, a quantity proportional to $| S^A - S^B |$ plays a role similar to the Haldane gap in the AFM spin ring. Moreover, a nonzero spin current exists at $T = 0$, again similar to the case of the AFM spin ring [14]. On the other hand, when the thermal energy is higher than the field-induced gap, the magnitude of the spin current is proportional to temperature T, similar to the case in the FM spin ring [13].

三、計畫成果自評

由上述的結果可以看出，我們的工作推廣了早先的研究工作。這對於國內外相關的後續研究工作有著相當程度的幫助。

此外，相關的研究成果[23] 即將刊登於 Phys. Rev. B。

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