Current-induced dynamics of magnetic hedgehog lattices

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Magnetic skyrmions and hedgehogs are topological spin textures exhibiting stable particle nature due to their topological protection, leading to their utilization as an information carrier. In a metallic magnet, these topological spin textures can be driven by applying an electric current, and hence their implications for novel spintronics devices have been proposed. Thus far, such current-induced drift motions have been mainly studied for the skyrmions in a two-dimensional magnet [1,2], while the systematic investigation for the three-dimensional (3D) hedgehogs remains largely unexplored. Unlike skyrmions, hedgehogs have singular points where the spin length vanishes in the 3D spin structures, and hence they are expected to bring about current-induced dynamics distinct from the skyrmions. In this study, we theoretically investigate the drift motions of the hedgehogs caused by an electric current in a model for metallic magnets, focusing on periodic arrangements of hedgehogs and antihedgehogs called the hedgehog lattices (HLs). The HLs have been discovered in both chiral and nonchiral magnets [3-5]. Through the numerical simulations based on the Landau-Lifshitz-Gilbert equation, we investigate the velocity of the drift motion while changing the amplitude and direction of the applied electric current. We find that a drift motion of the HL is caused in the longitudinal direction to the applied current above the threshold current density. The threshold value depends on the magnetic field and the direction of the electric current relative to the Dirac strings connecting the hedgehogs and antihedgehogs (Fig. 1). Furthermore, in the presence of the Dzyaloshinskii-Moriya interaction, we reveal that the HLs exhibit a drift motion transverse to the current direction. We call this the hedgehog Hall effect, in analogy with the skyrmion Hall effect [2,6]. Notably, the threshold current for the transverse motion is smaller than that of the longitudinal motion, resulting in the “perfect” hedgehog Hall effect with the maximally large Hall angle of half pi. In addition, we investigate how the lattice structures formed by the hedgehogs and antihedgehogs melt for the electric current density much larger than the threshold value. This study makes an important step to understanding the current-induced dynamics of the HLs and would shed light on the applications of the 3D topological spin textures to novel spintronic devices.

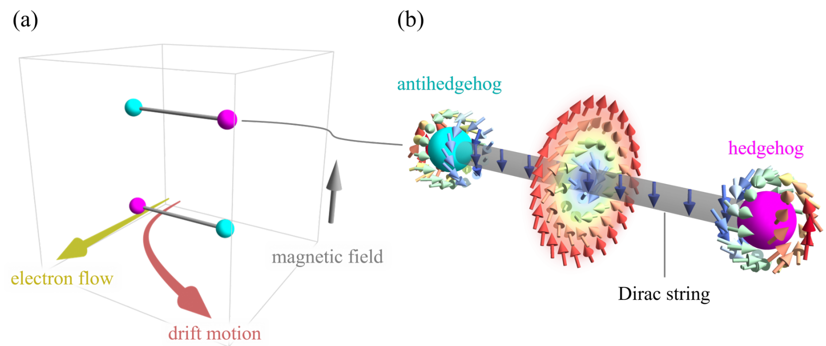

Fig. 1: (a) Schematic illustration of the drift motion of the HL induced by an electric current. The magenta and cyan spheres represent the hedgehog and antihedgehog, respectively. The gray tubes represent the Dirac string, which connects the hedgehog and antihedgehog. (b) Schematic illustration of the hedgehog, antihedgehog, Dirac string, and real-space spin configuration around the topological objects. The arrows represent the direction of spins and their color displays the z component. The Dirac string is composed of downward spins.

References

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