論文の内容の要旨

Mathematical aspects of spin-momentum locking: generalization to magnonic systems and application of orbifold to topological material science

（スピン運動量ロッキングの数理：マグノン系への一般化及びオービフォールドのトポロジカル物質科学への応用 ）

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The spin-momentum locking, in which electron spin depends on its momentum, has attracted much interest in recent condensed matter physics. In momentum space, this phenomenon is expressed as an interesting spin vector field. In particular, singular spin textures in momentum space have been extensively investigated in electron systems without spin rotational symmetry. In two dimensions, a spin vortex with the winding number +1 has been found in momentum space of the Rashba electron gas system and topological insulator surface state. In the presence of this spin structure, electric current induces spin polarization. This magnetoelectric effect is the so-called Rashba-Edelstein effect, and its efficient spin-charge conversion nature is useful in spintronics. In three dimensions, a spin monopole with the winding number ±1 has been discussed in the context of the topological semimetals. In realistic materials, a spin texture in momentum space is closely related to the band topology. In this sense, the spin-momentum locking plays an important role not only in spintronics but also in topological material science.

Although the spin vortices and monopoles in momentum space have been extensively investigated, previous studies have focused on structures with the winding number ±1. It is important to investigate various types of singular spin textures since they are expected to lead to new transport phenomena. Also in principle, the notion of the spin-momentum locking can be generalized to other quasiparticles that carry spin angular momentum. These two directions are main topics of this thesis.

In this thesis, we first introduce the basics of the spin-momentum locking and review two papers [1, 2] in Introduction. Then we move on to the following two topics.
(1) Generalization of spin-momentum locking to magnonic systems.
(2) Classification of the electron spin texture in three-dimensional momentum space under the space group symmetries by using the notion of the orbifold. The topic (1) is based on the paper [3].

In the topic (1), we present a theory of the magnon spin-momentum locking in the semiclassical regime. We define the magnon spin and give the conditions for it to be independent of momentum. Avoiding such no-go conditions, we construct several examples of the magnon spin-momentum locking. We find that the magnon spin depends on its momentum even when the Hamiltonian has the *z*-axis spin rotational symmetry, which can be explained in the context of a singular band point or a symmetry breaking. We find a high-winding number spin vortex (winding number: -2) in momentum space, which has not been found in electron systems. We also find that topology of momentum space imposes constraints on the spin configurations by using the Poincaré-Hopf index theorem. This fact is the starting point of the topic (2).

In the topic (2), we investigate electron spin textures in momentum space in the presence of three-dimensional space group symmetries. Since space group symmetries affect both momentum and spin, both the symmetries and topology of momentum space impose constraints on the spin texture. To describe this situation, we introduce the notion of the orbifold, which is a simple generalization of the manifold. We define the momentum space orbifold for space group symmetries, and map the spin texture on momentum space to the (pseudo-)vector field on the momentum space orbifold. We explicitly derive the constraints on spin textures for 24 symmorphic space groups by investigating the topology of 24 momentum space orbifolds. The derived constraints are useful to find Weyl points and new spin monopoles in momentum space.

[1] N. Okuma and K. Nomura, Phys. Rev. B **95**, 115403 (2017).
[2] N. Okuma, M. R. Masir, and A. H. MacDonald, Phys. Rev. B **95**, 115403 (2017).
[3] N. Okuma, Phys. Rev. Lett. **119**, 107205 (2017).