凝縮系物理学ゼミナール
Condensed Matter Seminar

Date: 13:30-15:00, Wednesday, 4 December 2024

Title: Lattice geometry, gauge transform, and supercurrent response

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Abstract:

The lattice geometry, which is the internal coordinates of the sublattice in the tight-binding model, are physically meaningful quantities. For example, it is obvious that the current operator depend on the lattice geometry. The lattice-geometry dependence of the current operator arises from the off-diagonal component of its matrix element, namely the Berry connection, which is the quantum geometric quantity. Therefore, physical quantities closely related to quantum geometry, such as the photocurrent, can depend on the lattice geometry. In superconductors, the supercurrent is described by the superfluid weight, which is also known to contain contributions from quantum geometry [1]. Therefore, the superfluid weight is expected to depend on the lattice geometry. Especially in flat-band systems, the quantum geometry determines the superfluid weight, and thus the lattice-geometry dependence of the superfluid weight is considered crucial. However, in the recent mean-field analysis, the superfluid weight has been shown to be independent of the lattice geometry even in flat-band systems [2]. Although the lattice-geometry independence of the superfluid weight has not been rigorously proven, this result implies the lattice-geometry independence of phenomena related to the supercurrent. Furthermore, the lattice-geometry dependence of other physical quantities may also be open to reconsideration, and the lattice geometry dependence/independence of physical quantities and their origins is an open question.

In this seminar, we point out the correspondence between the lattice geometry transformation and the gauge transformation. In particular, under uniform external fields, the lattice geometry transformation is equivalent to the gauge transformation in the absence of the electric and orbital magnetic fields. Therefore, it is concluded that the supercurrent responses, which do not require an electric field, are independent of the lattice geometry. Furthermore, we rigorously prove that the equation of motion for the Green function guarantees the lattice geometry invariance of the supercurrent responses. This proof is analogous to the Nambu's proof for the gauge invariance of the superfluid weight [3]. Finally, the lattice geometry independence of the supercurrent is demonstrated by the numerical calculations using the mean-field approximation.

References :

[1] P. Törmä, S. Peotta, and B. A. Bernevig, Nat. Rev. Phy. **1** (2022).
[2] K.-E. Huhtinen *et. al.*, Phys. Rev. B **106**, 014518 (2022).
[3] Y. Nambu, Phys. Rev. **117**, 648 (1960).