論文の内容の要旨

Searching for an emergent SU(4) symmetry in real materials

(現実の物質における創発 SU(4)対称性の探求)

氏　名　山田　昌彦

Beauty of mathematics appears everywhere in modern condensed matter physics, but the importance of the theory of higher-rank Lie groups has been ignored for a long time. The enhancement of the spin-space symmetry from the usual SU(2) to SU(N) with N > 2 is promising for finding nontrivial quantum spin liquids, but the realization of SU(N) spin systems in real materials is still challenging. Although there is a proposal in cold atomic systems, in magnetic materials with a spin-orbital degree of freedom it is difficult to achieve the SU(N) symmetry by fine tuning. Here we propose a new mechanism by which the SU(4) symmetry emerges in the strong spin-orbit coupling limit. In d^1 transition metal compounds with edge-sharing anion octahedra, the spin-orbit coupling gives rise to strongly bond-dependent and apparently SU(4)-breaking hopping between the J_{eff} = 3/2 quartets. However, in the honeycomb structure, a gauge transformation maps the system to an SU(4)-symmetric Hubbard model, which means that the system has a hidden symmetry in spite of its large spin-orbit coupling. In the strong repulsion limit at quarter filling, as expected in α-$ZrCl_3$, the low-energy effective model is the SU(4) Heisenberg model on the honeycomb lattice, which cannot have a trivial gapped ground state and is expected to host a gapless spin-orbital liquid. In such quantum spin-orbital liquids, both the spin and orbital degrees of freedom become fractionalized and correlated together at low temperature due

to the strong frustrated interactions between them. Similarly to spinons in pure quantum spin liquids, quantum spin-orbital liquids can host not only spinon excitations, but also fermionic “orbitalon” excitations at low temperature, which we have named here in distinction from orbitons in the symmetry-broken Jahn-Teller phases. In fact, the SU(4) Heisenberg model on the honeycomb lattice is known to host such gapless exotic excitations (spinons and orbitalons) by numerical calculations. By generalizing this model to other three-dimensional lattices, we also propose crystalline spin-orbital liquids protected by the combination of an emergent SU(4) symmetry and space group symmetries.