Symmetry theory of magnetism

Qihang Liu

Southern University of Science and Technology, Shenzhen 518055, *China*

E-mail: liuqh@sustech.edu.cn

Abstract

The physical properties in magnetic-ordered materials were ultimately believed to rely on the symmetry theory of magnetic groups. Recently, it has come to light that a more comprehensive group, known as spin (crystallographic) group, which combines separate spin and spatial operations, is necessary to fully characterize the geometry and underlying properties of magnetic-ordered materials such as altermagnets [1]. In this talk, we introduce recent developments in spin group theory, including an extensive enumeration of over 100000 spin space groups (SSGs) and their irreducible co-representations in momentum space, leading to more energy degeneracies that are disallowed by magnetic groups [2,3].

We further present the applications of spin groups in several aspects: (i) Based on whether the net spin magnetization is constrained to zero by SSG, we establish a stringent classification of the ferromagnetism-antiferromagnetism dichotomy. We further introduce an oriented SSG description, i.e., an SSG with a fixed magnetic orientation, which unifies the SSG and magnetic space group frameworks and clearly reveals the symmetry-breaking pathway induced by spin-orbit coupling [4]. (ii) Spin group theory triggers the emergence of the research area of "unconventional magnets", which simultaneously exhibit antiferromagnetic configurations while displaying properties reminiscent of ferromagnets. We discuss the symmetry design strategies and material pools for different facets of unconventional magnets, including spin splitting (altermagnets), quantum geometry, multiferroicity, and topological magnons [3,5-8]. We also introduce a homemade online program, FINDSPINGROUP (https://findspingroup.com/), which is applied to diagnose the symmetry classification of magnetic materials and related properties.

References

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