Altermagnetism and Beyond: from Spintronics to Spin Symmetries

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The discovery of altermagnetism has expanded the landscape of magnetic order, revealing a class of magnetic phases that combine key advantages of ferromagnets and antiferromagnets while exhibiting previously overlooked spin-polarization effects and couplings [1-2]. More broadly, it has opened a pathway toward a systematic classification of magnetic states based on the symmetries they preserve and break.

In this talk, I will introduce the framework of spin crystallography, which extends crystallographic principles to spin symmetries arising solely from spin order, independent of spin-orbit coupling, analogous to how unconventional superfluids and superconductors are classified by the symmetry of their order parameters. Spin crystallography has enabled the prediction and classification of d-, g-, and i-wave spin-polarized altermagnets and p-, f-, and h-wave spin-polarized antialtermagnets. These phases are distinguished by the nontrivial ways in which their spin-polarized states break spin-rotational, lattice, and time-reversal symmetries. This classification emerged from exploring the symmetry breaking required for unconventional spintronic effects [3-5], such as the crystal Hall effect and unconventional tunneling magnetoresistance, and has enabled the identification of hundreds of realistic material candidates, ranging from metals to insulators.

I will then discuss recent experimental observations of these unconventional magnetic states, focusing on their signatures in spin-polarized photoemission spectroscopy and evidence for their distinctive electronic structures in materials such as MnTe [6]. Finally, I will outline the opportunities that altermagnets and antialtermagnets offer for spintronics [3-5], multiferroics [7-8], topological states [9], and Ising superconductivity [10], highlighting how symmetry-guided materials design can enable new functionalities in quantum materials and future device concepts.

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