

Topological magnetism at surfaces

Topological orbital magnets at surfaces and interfaces

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In Short

- In non-coplanar spin structures such as skyrmions topological orbital magnetic moments occur even in the absence of spin-orbit coupling.
- Topological orbital magnets exhibit intriguing transport properties such as the topological Hall effect.
- We use density functional theory in combination with atomistic spin models to explore topological orbital magnetism in ultrathin films at surfaces and in 2D and bulk van der Waals materials.

Because of their intriguing topological and dynamical properties non-collinear spin textures such as magnetic skyrmions – localized, whirling spin structures – are of great fundamental interest as well as promising for numerous future spintronic applications ranging from data storage to neuromorphic or quantum computing [1,2]. The non-trivial spin topology of a skyrmion gives rise to an emergent magnetic field which causes the topological Hall effect [3]. This electronic transport effect is essential for potential applications since it allows for example electrical detection of single magnetic skyrmions.

Another key consequence of electron motion in the fictitious magnetic field is the topological orbital moment. Topological orbital moments can occur in non-coplanar spin structures even in the absence of spin-orbit coupling [3,4,6–9]. A prominent example of such a spin structure is the triple-Q state with tetrahedron angles between adjacent spins on a hexagonal lattice (see Fig. 1). This intriguing spin state has been predicted more than 20 years ago [10] but was only recently discovered experimentally in the ultrathin film system composed of a Mn monolayer on the Re(0001) surface [13]. Experimental evidence for the spontaneous topological Hall effect in the triple-Q state has recently also been given in the intercalated van der Waals magnet $\text{Co}_{1/3}\text{TaS}_2$ [14,15]. However, so far it has been elusive to directly reveal the topological orbital moments.

Topological orbital moments have also been studied only in a small number of systems to date. In this project we will explore the formation of topological orbital moments and their order in various types of spin structures and material systems such as

transition-metal interfaces, magnetic multilayers, and two-dimensional (2D) van der Waals (vdW) magnets and heterostructures. We will use first-principles electronic structure theory calculations based on density functional theory to obtain the electronic and magnetic structure of the systems and to calculate the spin and orbital moments.

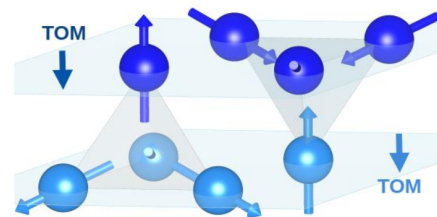


Figure 1: The image shows the magnetic moments in an atomic bilayer which exhibits the triple-Q state in both layers. The dark (light) blue spheres with arrows show the atoms of the upper (lower) layer with the magnetic moments. In both layers the magnetic moments exhibit tetrahedron angles. As highlighted by the gray transparent tetrahedron the angles for moments between the layers also exhibit tetrahedron angles. The resulting magnetic state possesses topological orbital moments (TOMs) in each of the two layers (see arrows on the upper right and lower left) which align parallel with respect to each other [11,12].

A goal of this project is to find new material systems with large topological orbital moments that allow manipulation by external fields. For this purpose, we will go beyond systems with a single magnetic layer to systems with multiple magnetic layers which can be realized at surfaces as well as in 2D vdW magnets. We will also address the role of spin-orbit coupling on the total orbital moment in non-coplanar spin states. Atomistic spin simulations will be used to study the formation of domain walls in non-coplanar spin states and the emergence of localized topological orbital magnetization. Within this project we will also explore possibilities to directly reveal topological orbital moments in future experiments by our collaboration partners e.g. using spin-polarized scanning tunneling microscopy.

WWW

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More Information

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Project Partners

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