3D nanomagnetism: Scientific and technological challenges and opportunities

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The study of three-dimensional magnetic nanostructures is a rapidly evolving field, offering a wealth of new physical phenomena stemming from the increased complexity of spin textures, topology, and frustration in three dimensions. The concept of chirality which requires three dimensions, is crucial in understanding various fundamental interactions in fields such as in cosmology and particle physics, the evolution of life in biology, or molecular chemistry. recently also attracted enormous interest in the magnetism community. By designing tailored three-dimensional nanomagnetic structures, including artificial spin ice systems or magnonics, one can unlock novel applications in magnetic sensor and information processing technologies, leading to improved energy efficiency, processing speed, and miniaturization of future spintronic devices. Another key approach in exploring and harnessing the full three-dimensional space is the use of curvature as a design parameter, where the local curvature impacts physical properties across multiple length scales, ranging from the macroscopic to the nanoscale at interfaces and inhomogeneities in materials with structural, chemical, electronic, and magnetic short-range order. This is particularly relevant In quantum materials, where correlations, entanglement, and topology dominate play a dominant role. The local curvature opens the path to novel phenomena that have recently emerged and could have a dramatic impact on future fundamental and applied studies of materials. Magnetic systems, in particular, hosting non-collinear and topological states, as well as artificial 3D magnetic nanostructures strongly benefit from treating curvature as a new design parameter to explore prospective applications in magnetic field and stress sensing, micro-robotics, and information processing and storage. To fully realize the potential of 3d nanomagnetism advances are needed in modelling/theory, synthesis/fabrication, and state-of-the-art nanoscale characterization techniques to understand, realize and control the properties, behavior, and functionalities of these novel magnetic nanostructures. I will summarize and review the challenges but also the opportunities ahead of us in the future exploration of nanomagnetism in three dimensions.

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