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OUT-OF-SURFACE VORTICES IN SPHERICAL SHELLS

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Magnetic vortices were intensively studied during last decades for the sake of applications in nanomagnetism as high-density magnetic storage devices [1] and miniature sensors [2]. Investigations of different aspects of magnetic vortex statics and dynamics were mainly restricted to flat structures. In such nanomagnets, the vortex appears as a ground state in sub-micrometer sized magnets due to a competition between the short-range exchange interaction and the long-range dipole interaction. The ground state of smaller samples is typically characterized by in-plane quasi-uniform magnetization. Contrary to in-surface, a quasi-uniform magnetization distribution in thin spherical shells is forbidden for topological reasons, instead two oppositely disposed vortices are expected.

We studied properties of magnetic vortices obtained in thin spherical shells with easy-surface anisotropy. Using anisotropic Heisenberg model, we vortex-type solutions. Contrary to vortices in flat magnets, there is interplay between the localized out-of-surface and the delocalized in-surface vortex structure. In other words, the vortex core plays the role of a charge source for the vortex phase structure. Structure of the vortex state of a spherical shell essentially depends on the relative magnetization directions (polarities) of the two vortex cores.

For the *case of equal polarities* ($p_1=p_2=p$) the vortex solution outside the vortex core can be written in the form

$$\Phi \approx \pm\frac{\pi}{2}\left(1 - p\vartheta_c\alpha \ln\tan\frac{\vartheta}{2}\right), \qquad \Theta \approx \frac{\pi}{2} \tag{1}$$

Here the angular variables Φ and Θ describe the distribution of the unit magnetization vector $\mathbf{m}$ over the spherical shell in the way $\mathbf{m} = (m_r, m_\vartheta, m_\chi) = (\cos\Theta, \sin\Theta\cos\Phi, \sin\Theta\sin\Phi)$, where the spherical frame of reference (r, ϑ, χ) is used with ϑ and χ being polar and azimuth angle, respectively. ϑ_c is the angular size of the vortex core and parameter α is solution of the equation $\alpha = \cos(\alpha\vartheta_c \ln\cot(\vartheta_c/2)\pi/2)$.

For the *case of opposite polarities* ($p_1 = -p_2 = p$) only the trivial solutions appear: $\Phi \equiv \pi$ for $p = 1$ and $\Phi \equiv 0$ for $p = -1$.

Thereby we show that the vortex on a spherical surface gains a coordinate and polarity-dependent turning of its phase. An interplay between topological properties of the vortex, namely, its polarity, and the curvature of the underlying surface results a breaks of the degeneration of the phase-like variable Φ with respect to the rotation by any constant angle Φ_0. This degeneration is known as well as for π_1-vortices in different media and for π_2-vortices in flat magnets. It is important to note that the angle Φ_0 in magnetic nanodisks determines the vortex chirality [3]. Thus one can speak about *polarity-chirality coupling*.

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