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INFLUENCE OF MAGNETIC AND STRAY FIELDS ON A BLOCH POINT STRUCTURE

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A Bloch point singularity can form a metastable state in a magnetic nanosphere. We derive analytically the shape of magnetization distribution of different Bloch points in spherical samples. We show that external gradient field can stabilize the Bloch point: the shape of the Bloch point becomes radial-dependent. We compute the magnetization structure of the nanosphere, which is in a good agreement with performed spin-lattice simulations.

Topological singularities are widely recognized as a key to understanding the behavior of a wide variety of condensed matter systems. The point singularities play a crucial role in quantum transitions in two-dimensional antifferromagnets, in surface states of superfuluid He-3 and in vortex polarity switching in ferromagnetic nanodots.

The concept of point singularities or Bloch points was introduced in magnetism by Feldtkeller [1]. In spherical frame of reference (r, ϑ, φ), for unit magnetization vector $\vec{m} = \vec{M} / M_S = (\sin\Theta\cos\Phi, \sin\Theta\sin\Phi, \cos\Theta)$, a Bloch point structure can be described as follows:

$$\Theta(\vartheta) = p\vartheta + \pi(1-p)/2, \Phi(\varphi) = q\varphi + \gamma, \quad p, q = \pm 1, \tag{1}$$

where rotation angle γ is determined only by magnetostatic interaction due to isotropy of exchange, and M_S is a saturation magnetization. Using a pole avoidance principle Feldtkeller derived [1] the rotation angle as $\gamma_F = 120^\circ$. Another approach was put forward by Döring [2], who determined the equilibrium angle $\gamma_D \approx 112^\circ$ by minimizing the inner part of the magnetostatic energy by integration over the sample volume while the outer part of stray field is ignored; the similar approach was used in quite recent paper [3] where a magnetization contraction was taken into account ($\gamma_{EV} \approx 113^\circ$).

We calculated exact form of magnetostatic energy for Eq. 1 by integration of magnetostatic potential: (i) the energy of the antivortex Bloch point ($q = -1$) does not depend on γ and $\mathrm{E}^{\mathrm{ms}}_{q=-1} = 7/30 \approx 0.23$; (ii) the energy of the vortex Bloch point ($q = 1$) essentially depends on the rotation angle, it has the form

$$\mathrm{E}^{\mathrm{ms}\,p}_{q=1}(\gamma) = \frac{1}{30}\left(7 + 4p\cos\gamma + 4\cos 2\gamma\right). \tag{2}$$

The equilibrium value of rotation angle γ_0 corresponds to the minimum of the energy (2). It gives $\gamma_0^{p=1} \approx 105^\circ$ and $\gamma_0^{p=-1} \approx 76^\circ$. Let us compare Bloch point energies (2) for above mentioned approaches: the energy of [1] Bloch point $\mathrm{E}^{\mathrm{ms}\,p}_{q=1}(\gamma_F) = 0.1$, for [2] Bloch point one

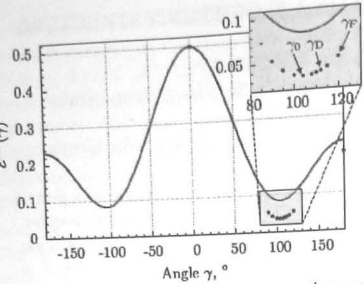

Fig. 1. The Bloch point energy vs rotation angle: analytical result (2) (solid curve) and simulations (symbols). Arrows show energy difference by results of Eq. (2) and works [F] and [D] in simulations.

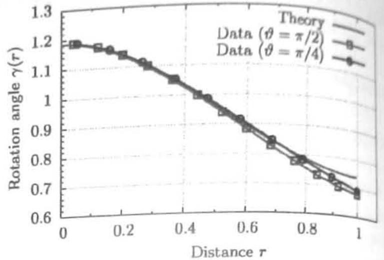

Fig 2. Radial dependence of rotation angle γ in spherical particle. Line: numerical integration of (2). Symbols: SLaSi simulations for crystallographic directions [110] and [111]. Distance is normalized to sphere radius R.

has $E^{ms}(\gamma_D) \approx 0.088$, the result by [3] is $E_1^{ms}(\gamma_{EV}) \approx 0.089$. The minimal energy has a Bloch point with the rotation angle γ_0: $E_{q=1}^{ms\,P}(\gamma_0) \approx 0.083$.

The Bloch point corresponds to a saddle point of energy functional and can be stabilized by gradient magnetic field in form $\mathbf{h} = 4\pi M_S b\mathbf{r}/R$,, b is a normalized field amplitude and R is a radius of the sample. In such field the Bloch point distribution becomes radial-dependent, which we take into account by the radial-dependent rotation angle $\gamma(r)$, see Ansatz (1). Using the variation approach one get the equilibrium value of rotation angle as a solution of nonlinear differential problem

$$\ell^2 \frac{d^2\gamma}{dr^2} + \frac{2\ell^2}{r}\frac{d\gamma}{dr} + \frac{1}{5}\sin\gamma + \frac{2}{5}\sin 2\gamma - \frac{br}{R}\sin\gamma = 0, \quad \left.\frac{d\gamma}{dr}\right|_{r=0,r=R} = 0, \tag{3}$$

where ℓ is exchange length. The analytical analysis of Eq. (3) can be provided in case of weak fields. The numerical integration of (3) is shown on Fig. 2.

In order to verify our results, we performed numerical spin-lattice simulations [4] for the sample with diameter $2R = 35a_0$ and $\ell = 3.95a_0$, where a_0 is a lattice constant. We compare analytical dependence (2) with the discrete energy of corresponded spin lattice, extracted from simulations, see Fig. 1. Both dependencies are matched in maximum at $\gamma = 0$. The Bloch point structure was numerically checked for radial-dependent Ansatz in the external field $b = 1$, see Fig. 2. One can see that numerical data are well confirmed by analytical curve $\gamma(r)$, calculated as numerical solution of (3).

References

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[2] W. Doering, Z. Appl. Phys, **39**, 1006 (1968).
[3] R. Elias, A. Verga, Europ. Phys. J. B, 1, (2011).
[4] SLaSi spin-lattice simulator http://slasi.rpd.univ.kiev.ua. Computing cluster of National Taras Shevchenko University of Kyiv (http://cluster.univ.kiev.ua), SKIT-3 Computing Cluster of Glushkov Institute of Cybernetic of NAS of Ukraine (http://icybcluster.org.ua).