Two-dimensionally modulated spin-structures at surfaces

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Motivation: searching for Skyrmions
Skyrmions are stable entities of a vector field characterized by a topological number, the skyrmion charge:
\[ S = \frac{1}{4 \pi} \oint \left( \frac{\partial n}{\partial x} - \frac{\partial m}{\partial y} \right) dx dy. \]

Such entities can be realized in magnetic structures, if appropriate magnetic interactions lead to a two-dimensional modulation of the magnetic structure. Typically, Heisenberg-type exchange or the Dzyaloshinskii-Moriya interaction (DMI) lead just to one-dimensionally modulated structures. A coupling between two spatial directions can be accomplished by higher-order spin interactions, which are, however, short ranged. Here, we show how these interactions form a nanoskyrmion lattice in an Fe monolayer on Ir(111).

1D example: stability of domain-walls
As a simple example, consider the stability of a magnetic domain bounded by two Néel-type domain-walls in a magnetic field:

The B-field cannot expel the domain if the walls have the same sense of rotation (a). The walls are stable (b). If the “chirality” of the walls is opposite, they can annihilate each other (d). Domain walls of an unique rotational sense are found in the system 2ML Fe/W(110). Their sense of rotation is determined by the Dzyaloshinskii-Moriya interaction.

[Image]

The basic magnetic interactions
Heisenberg-type exchange:
\[ H = \sum_{ij} J_{ij} \mathbf{S}_i \cdot \mathbf{S}_j \]

Dzyaloshinskii-Moriya interaction:
\[ H = \sum_{ij} D_{ij} \mathbf{S}_i \times \mathbf{S}_j \]

4-spin interaction:
\[ H = \sum_{ijkl} K_{ijkl} \left( \mathbf{S}_i \cdot \mathbf{S}_j \right) \left( \mathbf{S}_k \cdot \mathbf{S}_l \right) + \left( \mathbf{S}_i \cdot \mathbf{S}_k \right) \left( \mathbf{S}_j \cdot \mathbf{S}_l \right) - \left( \mathbf{S}_i \cdot \mathbf{S}_l \right) \left( \mathbf{S}_j \cdot \mathbf{S}_k \right) \]

The systems: Fe on Ir(111)

In scanning tunneling spectroscopy (STM) experiments, a square 15 atom magnetic unit cell was observed.

(K. v. Bergmann et al., PRL 98, 167203 (2007)).

Method & Results
All calculations were performed within DFT/LDA using the full-potential linearized augmented plane-wave (FLAPW) method as implemented in the FLEUR code (www.fleur.de).

- 1ML Fe on 4 layers Ir(111), up to 150 atoms
- Heisenberg-type exchange (left): calculation of homogeneous spin-spirals with the generalized Bloch theorem
- 4-spin interaction: comparison of different 2D structures in real space

Summary & Conclusions

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