NÉEL INSTITUTE, Grenoble

Topic for a PhD work

Emulating matter with magnetic meta-materials

General information

Funding for this full-time PhD thesis is secured
Required skills:

- Background in nanoscience / nanophysics / nanotechnology
- Background in magnetism will be useful

Starting date: October 2025
Contact (PhD supervisor): Nicolas Rougemaille (nicolas.rougemaille@neel.cnrs.fr)

Scientific context

In condensed matter physics, artificially made systems provide remarkable playgrounds for challenging our knowledge and seeking for novel properties. Unlike **natural** systems, i.e. systems that can be found in nature or synthesized chemically, **artificial** systems can be designed to study specific phenomena which would be challenging to probe otherwise. Artificial systems may be thus employed to emulate matter or to engineer properties that cannot be obtained with naturally occurring materials. Such artificial systems are often referred to as **meta-materials**, this term covering a wide range of architectures, generally produced by micro- or nano-fabrication techniques. The most emblematic case is probably that of optical meta-materials with negative refractive indices, offering new prospects for manipulating light. Artificial systems are of course not restricted to optical meta-materials, and **magnetic meta-materials** have been also largely used to emulate intriguing phenomena. The approach was particularly successful using **electron beam lithography patterned** 2D arrays of interacting nanomagnets. Compared to their natural counterparts, they provide the advantage that the magnetic state of each single meta-atom (the nanomagnet) can be determined unambiguously and in a routine fashion using **magnetic imaging** techniques (e.g. **magnetic force microscopy**). In addition, whereas chemically synthesized compounds exhibit exotic properties at very low temperatures (about 1 K or below), magnetic meta-materials can be imaged **at room temperature**. Finally, although magnetic meta-materials were initially made to mimic the unconventional, low temperature physics of certain bulk compounds, their flexibility, tunability and relative ease of fabrication allowed testing and revisiting many predictions but also exploring properties having no equivalent in natural materials. This is certainly why magnetic meta-materials still receive today considerable attention.

Positioning of the PhD project

The scientific community working on magnetic meta-materials has endeavored to demonstrate that certain exotic phases, as well as their excitations, could be prepared in a reproducible manner and imaged with high resolution, sometimes even in real-time. The work we have carried out for about 15 years [see selected references below] is part of this vivid, international research. This PhD project is devoted to the investigation of various emergent phenomena and properties in such magnetic meta-materials. The work will be conducted within an international collaboration involving three other groups. Although most of the work will be done in Grenoble, the PhD will have the opportunity to join other teams to perform complementary experiments.

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Selected references from our group

[1] Perrin *et al.*, Nature **540**, 410 (2016)
[2] Canals *et al.*, Nat. Comm. **7**, 1 (2016)
[3] Rougemaille *et al.*, Eur. Phys. J. B **92**, 62 (2019), **review article**
[4] Schanilec *et al.*, Phys. Rev. Lett. **125**, 057203 (2020)
[5] Schanilec *et al.*, Phys. Rev. Lett. **129**, 027202 (2022)
[6] King *et al.*, Phys. Rev. Lett. **131**, 166701 (2023)
[7] Alfonso-Moro *et al.*, Phys. Rev. Lett. **131**, 186201 (2023)
[8] Salmon *et al.*, Phys. Rev. B **109**, 054425 (2024)
[9] Coraux *et al.*, Phys. Rev. B **109**, 224422 (2024)
[10] Rougemaille and Coraux, **review article**, to appear in *2D and 3D Nanostructures: Structure, Properties and Applications*, Stanford Publishing