Annual Report 2023/2024

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1 Research activity

Magnetic skyrmions are particle-like spin textures with a nontrivial real-space topology [1, 2]. This property ensures excellent stability even at nanometer size, establishing skyrmions as promising information carriers in magnetic storage and processing devices. Cycloidal spiral magnets [3] host bimerons, a peculiar type of skyrmions constituted by a pair of vortex and antivortex with opposite out-of-plane magnetization in the cores. One of my research activities is studying the dynamics of these topological defects. Since the spiral background breaks translational symmetry, the bimeron structure (in particular, the net magnetic dipole moment) depends on the position. This is a major difference compared to the vastly studied skyrmion dynamics in a ferromagnetic background, which is translational invariant. An applied magnetic field can be used to align the bimeron dipole moment along a particular direction, thus fixing the bimeron position relative to the spiral. If the field rotates, the favored position moves. Hence, bimerons can be driven by a rotating magnetic field (e.g., due to a circularly polarized electromagnetic wave). Using the collective coordinates approach [4], I found two distinct dynamical regimes. At low driving frequencies compared to the strength of the field, the bimeron dipole moment rotates in sync with the magnetic field, and the velocity is proportional to the frequency. At high frequencies, the dipole moment rotates slower than the magnetic field, and the velocity decreases as the frequency increases. The transition between the two regimes corresponds to a sharp drop in the velocity, reminiscent of Walker breakdown [5].

In June and July, I visited the University of Groningen (Netherlands). Here, I collaborated with Prof. Maxim Mostovoy to propose a model explaining the giant magnetocapacitance observed in spiral multiferroics [6, 7]. These materials exhibit a strong coupling between magnetic and ferroelectric orders, allowing for cross-control. In particular, the ferroelectric polarization reorients when the applied magnetic field is higher than a critical threshold. Such a flop transition is concomitant with a huge enhancement of the dielectric constant. Since this is a first-order phase transition in a broad range of temperatures, the bulk domains cannot be responsible for this phenomenon. Domain walls (DWs) are the key to explaining such a giant magnetocapacitance. In the first year of Ph.D., I studied the multiferroic DWs where the ferroelectric polarization rotates by 180° [8]. Generalizing the analysis to include a magnetic field, I found that, approaching the flop transition from below, a 180° DW becomes a bound state of two 90° DWs. The closer the field is to the critical threshold, the weaker the bond between the two walls. At the flop transition, the pair of 90° DWs breaks. Since the distance between the walls in a pair is a mode associated with a ferroelectric polarization, the dielectric constant sharply increases. Consequently, this mechanism is a candidate for explaining the giant magnetocapacitance in spiral multiferroics. The next step of my research is to estimate the number of DWs per unit of length near the flop transition, which determines the strength of the DW contribution to the dielectric constant.

References

[1] A.M. Polyakov and A.A. Belavin, JETP Lett. **22**, 245 (1975).

[2] A. Bogdanov and A. Hubert, Journal of Magnetism and Magnetic Materials **138**, 255 (1994).

[3] T. Kimura *et al.*, Nature **426**, 55 (2003).

[4] O.A. Tretiakov *et al.*, Phys. Rev. Lett. **100**, 127204 (2008).

[5] N. L. Schryer and L. R. Walker, J. Appl. Phys. **45**, 5406 (1974).

[6] T. Goto *et al.*, Phys. Rev. Lett. **92**, 257201 (2004).

[7] F. Kagawa *et al.*, Phys. Rev. Lett. **102**, 057604 (2009).

[8] L. Maranzana, N. Nagaosa, and S. Artyukhin, arXiv:2403.11195 (2024)

2 Courses

I took the exams related to the following activities attended in the previous year:

- *School on quantum many-body phenomena out of equilibrium* (Ph.D. training school, ICTP)
  Report presented on October 10th, 2023
- *Crash course on theoretical condensed matter physics* (Ph.D. course)
  Exam passed on May 3rd, 2024

3 Research period abroad

- Visiting researcher at University of Groningen, Netherlands (Supervisor: Prof. M. Mostovoy)
  From June 1st to July 28th, 2024

4 Publications

- L. Maranzana *et al.*, *Bimeron dynamics in a spiral background*, in preparation.

5 Presentations

- DPG-Berlin: Talk given on March 20th, 2024
  Electric field-driven dynamics of meron domain walls in spin spiral multiferroics