Magnetic Skyrmion Lattice in Gd_2PdSi_3

In the last decade, nanometric spin vortices, referred to as magnetic skyrmions, in noncentrosymmetric magnets have been intensively studied. Some theories have predicted that magnetic frustration may also result in a lattice state of magnetic skyrmions. In this study we have found the emergence of magnetic skyrmion states in a frustrated centrosymmetric magnet Gd_2PdSi_3. The Hall resistivity is enhanced by the application of a magnetic field of 0.5–1.0 T along the hexagonal c-axis at low temperatures. In this phase, triple in-plane spin modulation of (q 0 0), (0 q 0), and (q −q 0) is confirmed by resonant X-ray scattering.

Magnetic skyrmion lattice has been found in cubic chiral MnSi [1] and many other noncentrosymmetric magnets. The lack of inversion symmetry produces the uniform antisymmetric exchange interaction, often called Dzyaloshinski-Moriya interaction, which prefers canting between neighboring spin moments. The competition between ferromagnetic exchange interaction and antisymmetric exchange interaction may result in a helimagnetic state. The helix is modified by the application of a magnetic field and sometimes transformed to the triangular lattice of magnetic skyrmions. However, the helimagnetic state is also found in frustrated magnets. Some theories hence propose the emergence of the skyrmion lattice state in a frustrated magnet in a magnetic field [2, 3]. Nonetheless, no experimental observation has been reported.

Gd_2PdSi_3 consists of Gd triangular lattice and $Pd_{1/4}Si_{3/4}$ honeycomb network. Previous studies showed metamagnetic transitions as well as modulation in Gd moments probably due to the so-called Ruderman-Kittel-Kasuya-Yosida (RKKY) type interaction [4]. We grew single crystals and investigated magnetic and transport properties in detail [5]. Figure 1 shows the magnetization and Hall resistivity at 2 K. The magnetic field is applied along the *c*-axis. Two-step metamagnetic transitions are discernible as anomalies at 0.5 T and 1.3 T. It is interesting to note that Hall resistivity exhibits an enhancement in the intermediate-field phase.

The measurement of resonant X-ray scattering was performed on BL-3A. A single crystal with widest planes of (1 1 0) was loaded in a cryostat with an 8-Tesla superconducting magnet. A magnetic field was applied along the *c*-axis. The X-ray photon energy was tuned at the Gd L_2 absorption edge (7.932 keV). The polarization of the incident beam was parallel to the scattering plane (or so-called π polarization). The polarization of the scattered beam was analyzed by pyrolytic graphite.

We explored superlattice reflections around the (220) reflections and found peaks at (1.86, 2, 0), (2, 1.86, 0), and (2.14, 1.86, 0), while no peak was observed along the (2-q, 2-q, 0) line in the reciprocal space. We confirmed that the superlattice peak disappears in the paramagnetic phase above 21 K. We compare the intensities of the superlattice reflections around (0, 4, 0), (2, 2, 0), and (4, 0, 0) in the intermediate-field phase with two magnetic models: triple proper screw modulation and triple cycloidal modulation, as shown in the left panel of Fig. 2. In the models, we assume that the amplitudes should be identical. The experimental result agrees well with the triple-screw modulation model. The right upper panel of Fig. 2 shows the results of polarization analyses of several superlattice reflections. The intensity of (2, 1.86, 0) reflection in the π-σ' channel is largely suppressed. Since the wavevector of the incident beam is almost parallel to the *b**-axis for the reflection, the intensity of the π-σ' channel nearly corresponds to the longitudinal spin modulation, which is absent in the proper screw. We hence conclude that the intermediate-field phase is the triangular lattice state of Bloch-type magnetic skyrmions, as shown in the right bottom panel of Fig. 2.

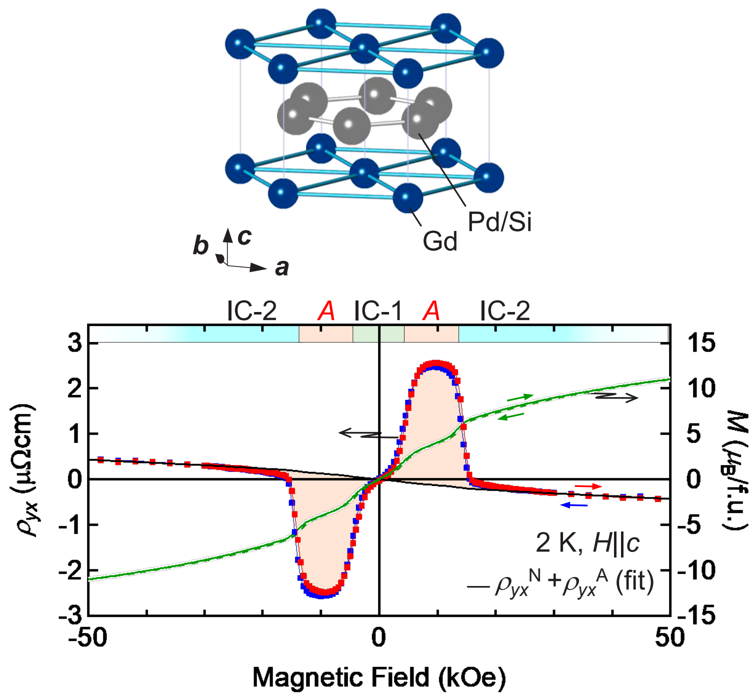

Figure 1: (Upper panel) Crystal structure of Gd_2PdSi_3. (Lower panel) Magnetization (thin line) and Hall resistivity (dots) in Gd_2PdSi_3 when sweeping a magnetic field along the *c*-axis at 2 K. Excerpt from Ref. [5].

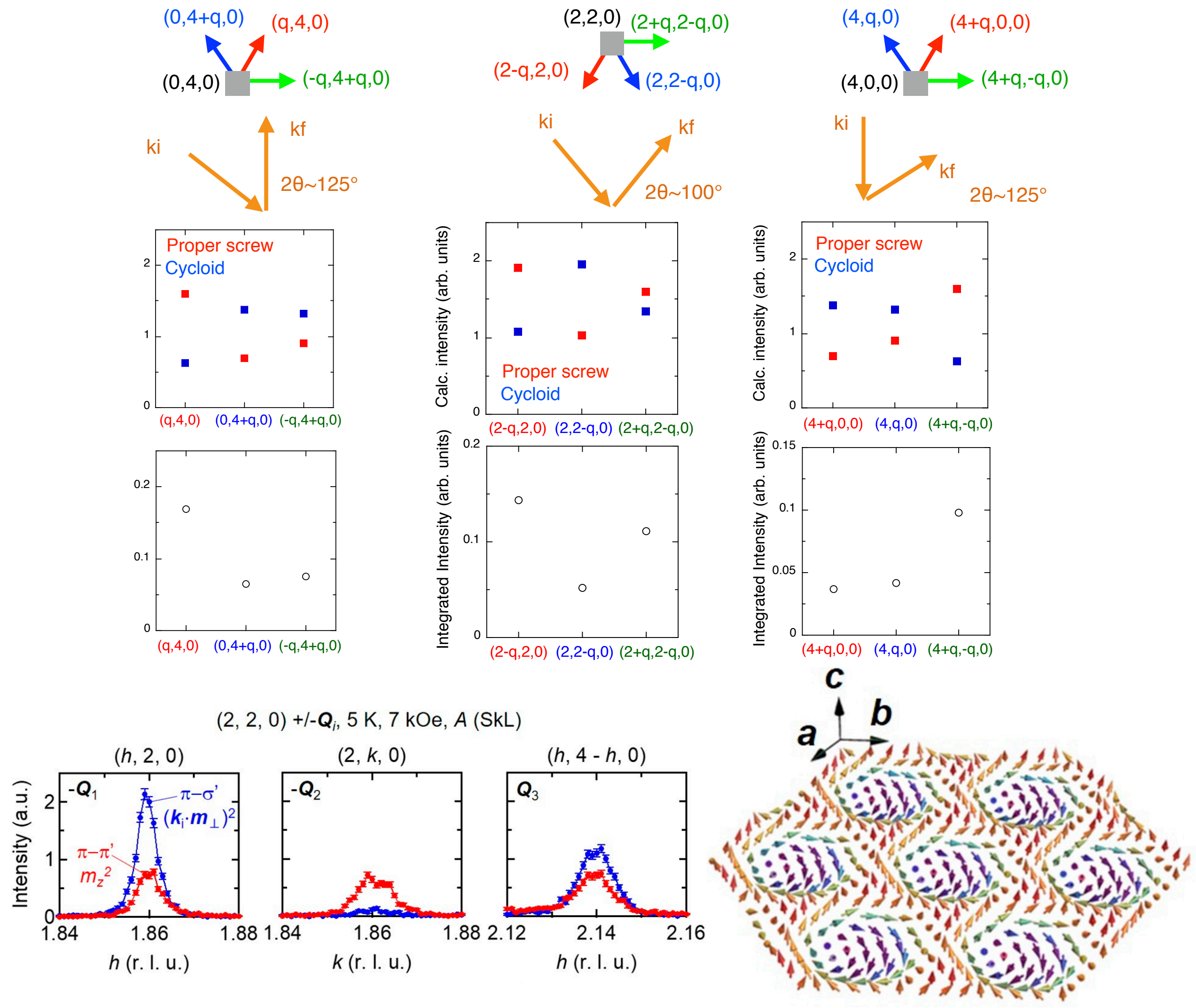

Figure 2: (Upper panel) Comparison of the intensities of superlattice reflections obtained by the present measurement with two models (see main text). (Lower left panel) Polarization analysis of superlattice reflections. Excerpt from Ref. [5]. All the data in this figure are for the intermediate-field phase.

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T. Kurumaji[1], T. Nakajima[1], M. Hirschberger[1], A. Kikkawa[1], Y. Yamasaki[1, 2], H. Sagayama[3], H. Nakao[3], Y. Taguchi[1], Y. Tokura[1, 4] and T. Arima[1, 4] ([1]RIKEN-CEMS, [2]NIMS, [3]KEK-IMSS-PF, [4]The Univ. of Tokyo,)