Uniaxial stress control of intricate magnetic phases in $EuAl_4$

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The centrosymmetric tetragonal itinerant magnet $EuAl_4$ has garnered increasing attention as a platform for various intriguing physical phenomena, such as the emergence of charge density wave (CDW) [1] and magnetic skyrmions [2]. In zero field, a multi-step phase transition occurs from the paramagnetic phase to the double-**Q** vortex phase (VII), double-**Q** meron/antimeron phase (VI), and single-**Q** spiral phases (V and I) as the temperature decreases. During this process, the **Q**-vector changes from **Q** = (0.085, ±0.085, 0) in phases VI and VII to **Q** = (0.17, 0, 0) in phase V, and eventually **Q** = (0.194, 0, 0) in phase I at 5 K. Furthermore, the phase transition from phase VI to V accompanies a tetragonal-to-orthorhombic structural transition characterized by a B_{1g}-type distortion of ~0.2%, highlighting the importance of spin-lattice coupling. Our previous resonant x-ray scattering experiment revealed that the magnetic modulation propagates along the elongated *b*-axis in phases I and V, as shown in Fig. 1(a) [3]. These characteristics suggest the potential for controlling the versatile magnetic phases in $EuAl_4$ using uniaxial stress.

To investigate this, we performed single-crystal neutron scattering experiments under applied uniaxial stress. The experiments were carried out using a triple-axis spectrometer at PONTA(5G) in JRR-3. The sample with the dimension of $2.0\times1.8\times0.5$ mm^3 was mounted in a clamp-type uniaxial-stress cell, with the $(H, 0, L)$ horizontal scattering plane, as depicted in Fig. 1(b). Compressive stress was applied along the [010] direction. Based on the relationship between the **Q** vector and lattice distortion [Fig. 1(a)], we expected the **Q** vector to align within the scattering plane under uniaxial stress in this geometry. The spectrometer was operated in the two-axis mode, with an incident neutron beam energy of 30.5 meV. The sample was cooled to 2 K using an orange cryostat.

Figure 1(c) summarizes the zero-field magnetic phase diagram under various strengths of uniaxial stress, σ. As the stress increases, a systematic increase in the q value in phase I, as well as an increase in the transition temperature between phases V (or I) and VI, was observed. Notably, phases I and V coexist at $\sigma = 20$ MPa, and eventually phase V disappears at $\sigma = 50$ MPa. Recently, a chirality switch between phases I and V was reported [4]. Our findings suggest that uniaxial stress can control not only the direction of the **Q** vector and the magnitude of the modulation but also the helicity of the magnetic phases in $EuAl_4$.

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[2] R. Takagi *et al.*, Nat. Commun. **13**, 1472 (2022).
[3] M. Gen *et al.*, Phys. Rev. B **107**, L020410 (2023).
[4] H. Miao *et al.*, Phys. Rev. X **14**, 011053 (2024).

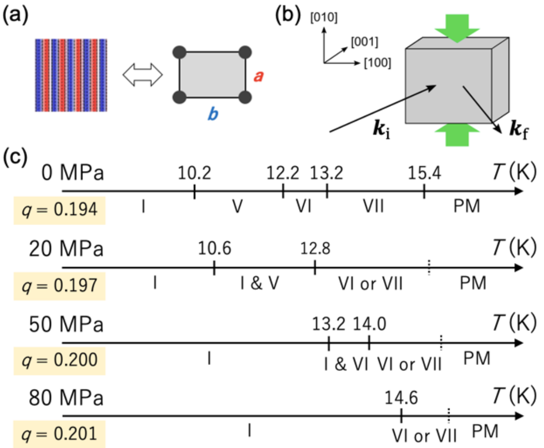

Fig. 1. (a) Relationship between the magnetic structure and orthorhombic lattice distortion in the single-**Q** spiral phases (I and V) [3]. (b) Geometry of the neutron scattering experiments under uniaxial stress. (c) Stress dependence of the magnetic phase diagram of $EuAl_4$ in zero field revealed in this study.