Research Group for Strongly Correlated Actinide Science

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Materials contain a huge number of electrons, typically in the order of Avogadro's number. In actinide materials, the electrons are strongly correlated with each other, and various exotic phenomena, such as spin-triplet topological superconductivity (SC), novel magnetism, and higher-rank multipolar ordering, emerge from the strong interactions. By means of advanced experimental and theoretical approaches, our research group tries to understand the rich physics of correlated actinide materials.

Ferromagnetic crossover observed inside ferromagnetic order of U_7Te_{12} [1]

U_7Te_{12} is ferromagnet with three non-equivalent uranium crystallographic positions, two distinctive ferromagnetic (FM) orderings at different temperatures perpendicular to each other.

In ordinary ferromagnets at temperatures below the Curie temperature (T_C) magnetic moments point in the same direction called easy magnetization axis. By application of external magnetic field, the FM second order phase transition at T_C changes to crossover due to external magnetic field breaking time-reversal symmetry.

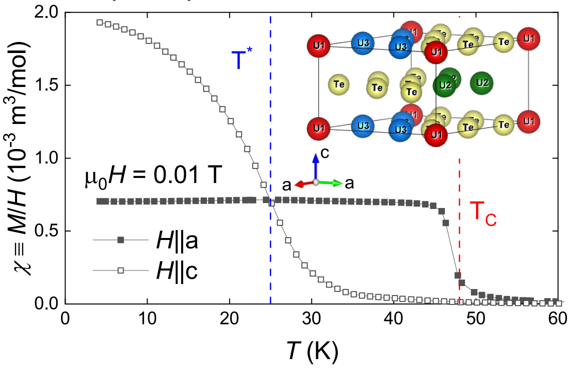

Fig. 1 Temperature dependence of magnetic susceptibility of two perpendicular axes *a* and *c* for U_7Te_{12}. The data for a-axis (black) show FM transition at 48 K while data for c-axis (white) show FM transition at 26 K. In the inset we show crystal structure of U_7Te_{12} with distinguished nonequal U positions.

In U_7Te_{12} at T_C = 48 K magnetic moments order along the *a*-axis, while at 26 K magnetic moments order along the *c*-axis (Fig. 1) without any sign of reorientation [1]. The different ordering direction and temperatures are results of different nonequal uranium positions creating two semi-independent magnetic sublattices. No sign of entropy change is found around 26 K, excluding any phase transition and suggests that ordering at 26 K is FM crossover in zero external magnetic field induced by time-reversal symmetry breaking at T_C. The uranium magnetically ordering at T_C creates internal magnetic field, which breaks time-reversal symmetry and leads to crossover at 26 K.

Interestingly, the local symmetry at T_C is lowered much more than required for FM ordering but the lower symmetry ensures the crossover nature of FM transition at 26 K, suggesting another mechanism might be in play at T_C.

The case of U_7Te_{12} is unique and interesting as two separate magnetic orderings with perpendicular easy magnetization axes coexisting in one material. It is unusual and not well investigated phenomena due to lack of investigation into materials with multiple crystallographic positions of magnetic ions and the complexity of such investigation.

Change of superconducting character in UTe_2 induced by magnetic field [2]

SC occurs when a coherent quantum fluid is formed from electron pairs. In most superconductors, although the total spin (S) of the pairs is in the singlet state (S =0), it is also possible to be in the triplet state (S=1). Such superconductors, called spin-triplet superconductors, are coherent quantum fluids with spin and orbital degrees of freedom. Spin-triplet SC would involve rich physics but are very rare. The recent discovery of FM superconductors, in which the ferromagnetism and SC arise from the same electrons, has made it possible to study the spin-triplet pairing state in detail. Additionally, a spin-triplet SC candidate UTe_2 has been more recently discovered with a relatively high SC transition temperature of 1.6–2.1 K.

One of the most characteristic features of UTe_2 is a magnetic field (H)-boosted SC, when the H (>16 T) is applied exactly parallel to the *b* axis (Fig. 2). In this study, we performed magnetic susceptibility and nuclear magnetic resonance measurements to understand the SC properties as well as the spin state of the high-field SC (HHSC) phase. We found that, up to 24.8 T, the HHSC state has bulk nature and is quite sensitive to the H angle and that its SC character is different from that in the low-field SC (LHSC) state. We also revealed that the dominant spin component of the spin-triplet pair is along the *a* axis in the LHSC state but is changed in the HHSC state along the *b* axis. Our results indicate that the H-induced multiple SC phases originate from the remaining spin degrees of freedom.

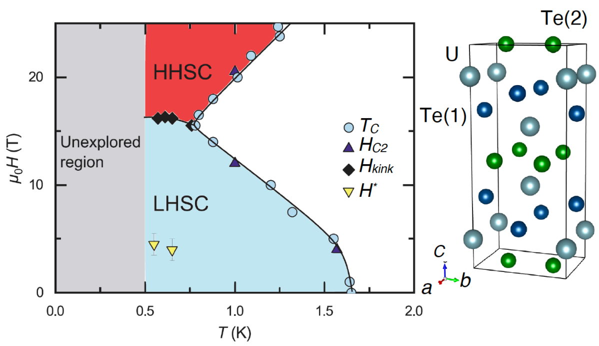

Fig. 2 (left) H-T phase diagram of UTe_2 under H applied exactly parallel to the *b* axis. The SC transition temperature (T_c) and the upper critical field (H_{c2}) are determined from the T and H dependences of magnetic susceptibility, respectively. Anomalies are also observed in the susceptibility measurements at H_{kink} and H^* [2]. (right) Schematic view of the crystal structure of UTe_2.

References

[1] P. Opletal *et al.*, J. Phys. Soc. Jpn. **92**, 034704 (2023).
[2] K. Kinjo *et al.*, Phys. Rev. B **107**, L060502 (2023).