NMR study of spin-triplet superconductivity in uranium-based materials

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While ferromagnetism and superconductivity are generally exclusive to each other, these two phenomena coexist on a microscopic scale in some uranium-based materials, so-called "ferromagnetic superconductors" UGe_2, UCoGe and URhGe. A characteristic feature of the materials is that they exhibit very large upper critical fields of superconductivity, by far exceeding the ordinary Pauli paramagnetic limit for spin-singlet pair, providing a strong indication of an exotic, spin-triplet pairing (Fig.1).

In November 2018, S. Ran et al. in University of Maryland reported evidence for superconductivity in a uranium-based material UTe_2, exhibiting rather high transition temperature of 1.6 K [1]. Their finding was soon after confirmed by D. Aoki et al in Tohoku University [2]. While the ground state of UTe_2 is paramagnetic, not ferromagnetic, the material still exhibits a very large upper critical field of the superconductivity, similar to the ferromagnetic superconductors. UTe_2 is thus suggested to host the spin-triplet pairing. Further discovery of field-induced superconductivity above 40 T highlights a close interplay between superconductivity and magnetism in UTe_2 [3].

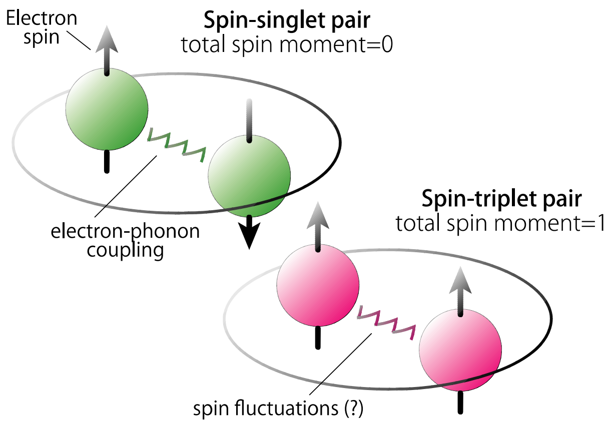

Fig.1 In the superconducting state, two electrons form the Cooper pair with making collective motion. In conventional spin-singlet state, the electron spins of the pairs are all antiparallel and the total spin moment is zero. On the other hand, in the spin-triplet state, the spins are parallel and the total spin moment is one.

In this study, in order to elucidate the mechanism of the unconventional superconductivity in UTe_2, we have performed ^{125}Te-NMR experiments using a high-quality single crystal [4, 5]. The crystal structure of UTe_2 is the body-centered orthorhombic structure, where Te atoms occur at two different sites: Te1 and Te2 sites with point symmetries *mm*2 and *m*2*m*, respectively. The inset of Fig.2 shows an example of NMR spectrum measured with field along the crystal *b*-axis [4]. The spectrum consists of two distinct peaks arising from the Te1 and Te2 sites. The narrow NMR lines point to the high quality of our single crystal.

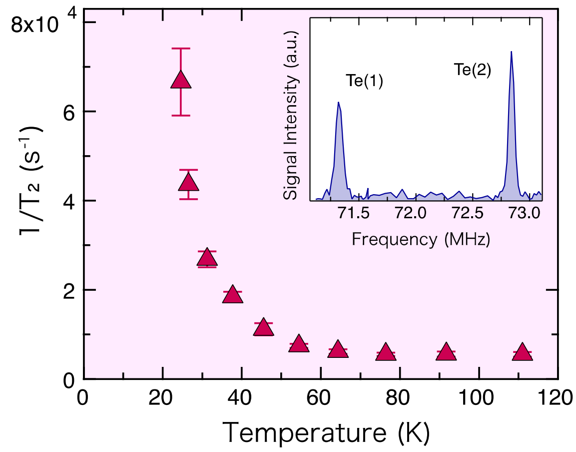

Fig.2 The temperature dependence of the spin-spin relaxation rate, $1/T_2$ obtained for fields applied along the a-axis [4]. The inset shows an example of NMR spectrum measured with field along the *b*-axis.

In the paramagnetic state, the NMR Knight shift K and the spin-lattice relaxation rate, $1/T_1T$ confirmed a moderate Ising-type anisotropy for both the static and dynamical susceptibilities above 20 K [4]. On the other hand, a sudden increase of the spin-spin relaxation rate, $1/T_2$ toward 20 K demonstrates the development of strong longitudinal magnetic fluctuations along the *a*-axis at very low frequency (Fig.2). The NMR data suggests that UTe_2 is close to a ferromagnetic instability, where a characteristic crossover temperature for spin fluctuations exists around 20 K.

Theoretically, the spin-triplet superconductivity is tightly connected to an exotic pairing mechanism for superconductivity: the superconducting pairs are mediated via spin fluctuations rather than by ordinary electron–phonon coupling [6]. Our results imply that the spin fluctuations near a ferromagnetic quantum critical point are at the origin of the spin-triplet pairing in UTe_2.

References

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