Summary of thesis: Nuclear Magnetic Resonance Studies on Multiple Superconducting Phases in UTe_2

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In this thesis, I report the superconducting properties in UTe_2 studied with nuclear magnetic resonance measurements. In superconductivity, two electrons form a pair called the "Cooper pair". Hence, superconductivity is classified into two categories: spin-singlet or spin-triplet superconductivity. In spin-triplet superconductors, the total spin angular momentum $\boldsymbol{S}$ is 1, resulting in the remaining of spin and orbital degrees of freedom. Due to these degrees of freedom, unusual behaviors such as multiple superconducting (SC) phases and the SC-SC transition induced by the magnetic field (H) are expected. However, there are few candidates for spin-triplet superconductors, and thus, spin-triplet multiple SC phases have not been intensively investigated so far.

In 2018, S. Ran *et al*. discovered the superconductivity in UTe_2 with its superconducting critical temperature T_c ~ 1.6 K[1]. UTe_2 is a leading candidate for the spin-triplet superconductor because the physical properties are very similar to those in the U-based ferromagnetic superconductors: magnetic properties and the anisotropy of the upper critical field (H_{c2}) of superconductivity, especially H-boosted superconductivity under the b-axis field, and the extremely large upper critical field (H_{c2})[1]. Furthermore, recent nuclear magnetic resonance (NMR) measurements revealed the tiny change or absence of the change in the spin susceptibility, supporting the spin-triplet scenario[2-4].

In UTe_2, multiple SC phases induced by the b-axis high magnetic field above 16 T (HFSC) or pressure above 0.3 GPa (SC2) were observed as shown in Fig. 1. To investigate their SC properties, especially the spin state in these phases, we performed the ^{125}Te-NMR measurements under a high H[5] and high pressure[6].

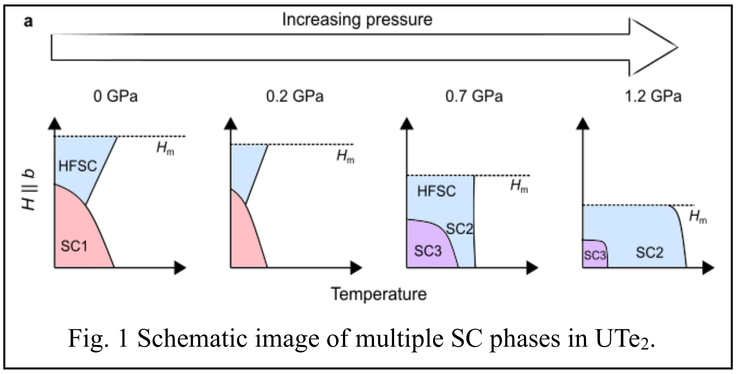

Fig. 1 Schematic image of multiple SC phases in UTe_2.

Chapter 6: Change of superconducting character in UTe_2 induced by magnetic field

For high-H measurement, above 20 T, the change in the NMR Knight shift (ΔK) below $T_c(H)$, which is proportional to the change in the spin susceptibility in the SC state, becomes zero, evidencing the SC spin rotation induced by the high *H*.

Chapter 7: Drastic change in magnetic anisotropy of UTe_2 under pressure revealed by ^{125}Te-NMR

and

Chapter 8: Superconducting-spin rotation in spin-triplet multiple superconducting phases in UTe_2

Under high pressure, the new SC phases are observed above 0.3 GPa (SC2, SC3 in Fig. 1), and superconductivity suddenly disappears above 1.6 GPa. Our NMR results under pressure above T_c revealed that the electronic state dramatically changes above 1.6 GPa, and that superconductivity occurs only in the heavy-fermion state. [6].

In the superconducting state under pressure (SC2), the NMR Knight shift does not show any anomaly at T_c. After subtracting the temperature dependence of the normal state, ΔK ascribed to the superconductivity is almost zero, indicating the superconducting spin is almost aligned to the *b* axis. In addition, below 0.5 K, near the transition temperature from SC2 to SC3, the NMR Knight shift shows a clear decrease and the line width of the NMR spectrum suddenly increases. In contrast to the conventional superconductivity, the line-width increase in SC3 is proportional to applied *H*. These features may come from the time-reversal symmetry-breaking superconductivity due to the mixture of SC order parameters of SC1 and SC2 in SC3 state[7].

References

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