Research Group for Materials Physics for Heavy Element systems

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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.

Slow electronic dynamics detected in spin-triplet topological superconductor UTe_2 [1]

A recently discovered heavy-fermion superconductor UTe_2 attracts particular attention, because of the strong possibility of spin-triplet Cooper pairing. In conventional, spin-singlet SC, the spins of Cooper pairs are all antiparallel, and the total spin moment equals zero. In spin-triplet SC, instead, spins are parallel and the total spin equals one. In this study, to clarify the mechanism of spin-triplet SC, we performed ^{125}Te-NMR experiments on a ^{125}Te-enriched single crystal of UTe_2 [1]. The enrichment of ^{125}Te largely enhanced the intensity of the NMR signal, allowing us to extend the measurement of the NMR spin-spin relaxation rate ($1/T_2$) to a lower field (*H)* and temperature (T) than a previous report [2].

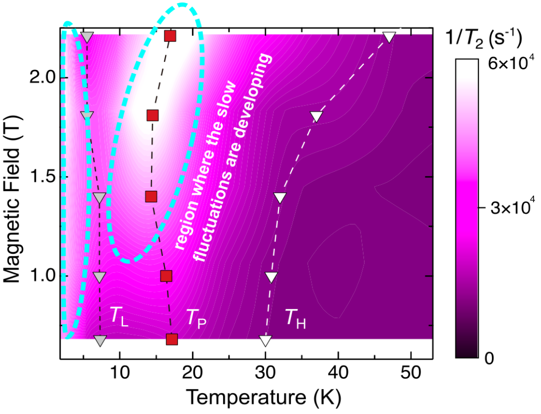

Fig. 1 T–H phase diagram with the contour plot of $1/T_2$ for $H//a$ [1]. The graph shows the evolution of three experimental temperatures T_H, T_P, and T_L, where subscripts stand respectively for 'High', 'Low' and 'Peak'. $1/T_2$ increases gradually below T_H and exhibits a broad peak at T_P. By further decreasing T, $1/T_2$ increases again below T_L.

In Fig. 1, we present the phase diagram of UTe_2 in magnetic fields applied along the crystal a-axis ($H//a$). The H and T dependences of $1/T_2$ reveal the emergence of slow electronic dynamics in the paramagnetic state below about 30 K [1]. The observed slow fluctuations are concerned with a successive growth of long-range electronic correlations below T_H. Our NMR experiments further revealed that tiny amounts of disorder or defects locally disturb the long-range electronic correlations and develop an inhomogeneous electronic state at low temperatures. We suggest that UTe_2 would be located on the paramagnetic side near an electronic phase boundary, where either the magnetic or Fermi-surface instability would be the origin of the characteristic fluctuations.

Nonmagnetic Mott insulating phase in an orbitally degenerate electron system with frustration [3]

The Mott transition, a metal to non-metal change in a material's behaviour, is one of the most remarkable phenomena emerging from electron correlations. A typical example is the single-orbital Hubbard model at half-filling, where the average electron number per site, n, is 1, although some sites may host 2 or 0 electrons. According to band theory, this system should be a metal since only half of the band is filled. However, if the onsite Coulomb interaction U is sufficiently large, almost all sites are occupied by a single electron, and the system is expected to become insulating. This insulating state is called the Mott insulator. Several theories developed for this many-body problem indicate that the Hubbard model predicts the Mott transition when a paramagnetic (PM) state is assumed. However, the ground state of the model is an antiferromagnetic (AF) insulator, which can be regarded as a band insulator rather than a Mott insulator. Thus, to realize the Mott transition, it is necessary to destabilize the AF state. Indeed, by introducing frustration with the next-nearest-neighbor-hopping integral (denoted as t'), it was shown that the AF phase shrinks, and the Mott transition takes place.

In this theoretical study, we extend the research on the Mott transition to the two-orbital model. Without frustration, the ground state is a ferromagnetic (FM) state with orbital order at n = 1. We find that the FM phase shrinks by increasing t' since this FM phase is supported by the staggered order of the orbital degrees of freedom. As a result, we find that the Mott transition occurs for large t' values (Fig. 2). This study revealed that the manifestation of the Mott transition is not limited to the simple single-orbital case and extends the research field of Mott physics to multiorbital systems.

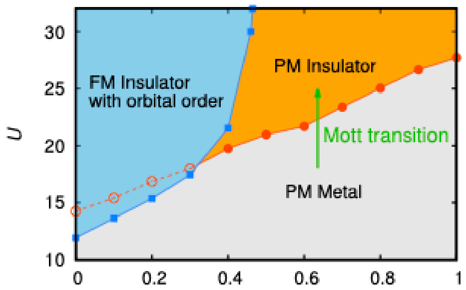

Fig. 2 Phase diagram for an orbitally degenerate electron system with frustration. The calculations predict a PM insulating phase (shown in orange), that is, a nonmagnetic Mott

References

[1] Y. Tokunaga *et al.*, J. Phys. Soc. Jpn. **91**, 023707 (2022).
[2] Y. Tokunaga *et al.*, J. Phys. Soc. Jpn. **88**, 073701 (2019).
[3] K. Kubo, Phys. Rev. B **103**, 085118 (2021).