Research Group for Materials Physics for Heavy Element systems

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In heavy element systems, valence fluctuations, the Kondo effect, and the RKKY interaction compete with one another. Because of this, exotic behaviors such as quantum critical points, heavy fermions, non-Fermi liquids, anisotropic superconductivity, and multipolar ordering appear when such competition is strong. By means of advanced experimental and theoretical approaches, our research group tries to clarify these exotic behaviors due to the "many-fold" character of both 4 *f* and 5*f* compounds, including transuranium.

Spin fluctuations as driving force of superconductivity in uranium-based ferromagnetic superconductors [1]

Attractive interaction responsible for superconducting (SC) pairs is mediated by lattice vibrations (phonons) in conventional spin-singlet superconductors (Fig. 1). The strength of this interaction is generally assumed to be field-independent, since the lattice vibrations are not directly coupled to applied magnetic field. In the case of Uranium-based ferromagnetic (FM) superconductors UGe_2, URhGe, and UCoGe, however, the interaction of spin-triplet pairs is supposed to be mediated by the exchange of FM spin fluctuations, whose excitation spectrum can be modified strongly by magnetic field. This suggests the possibility that their pairing interaction is also strongly affected by magnetic field.

In this study, using NMR technique, we have investigated the field effect on the FM spin fluctuations and thus the pairing interactions in URhGe and UCoGe. These two superconductors have the same crystal structure of the orthorhombic TiNiSi type and are both weak itinerant ferromagnet with Ising anisotropy along the same crystal axis. The compounds thus offer similar bases for the SC mechanism. However, their upper critical field H_{c2}, one of the most fundamental SC parameters, exhibits some

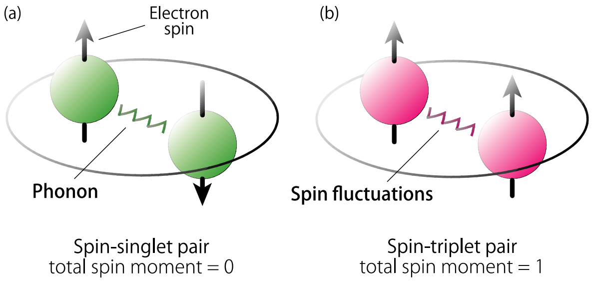

Fig. 1 Two types of superconducting electron pairs. In general, superconducting pairs adopt a spin-singlet state, in which the spins of the pairs are all antiparallel (a). However, in some uranium compounds, superconducting pairs adopt a spin-triplet state, in which the spins of the pairs are all parallel (b).

remarkable difference.

Our measurements of the field-angular dependence of NMR spin-lattice relaxation rate $1/T_1$ in URhGe revealed that spin fluctuations in FM state are robust against magnetic field applied any directions. This possess a strong contrast to the case of its sister compound UCoGe, in which the rapid suppression of the FM spin fluctuations by a tiny applied field along the easy magnetization axis has been observed. We show that such a difference is indeed reflected in the above mentioned two distinct phase diagrams of the H_{c2} and hence provides further experiment support for the mechanism of the superconductivity mediated by the FM spin fluctuations.

Universal scaling behavior under pressure in a prototypical 4*f* heavy fermion antiferromagnet $CeRh_2Si_2$ [2]

The case of an antiferromagnetic (AFM) heavy fermion (HF) is considered as a standard example to realize a quantum phase transition where the AFM transition occurs at $T_N = 0$ by applying pressure. At high temperatures, the system is in the fully incoherent regime with local moments. As the temperature decreases below $\sim T_0$, which is the energy scale of Kondo interactions, the local moments are gradually screened and counted in the Fermi volume. Conversely, in the local quantum criticality framework, the Kondo singlet is supposed to be critically destroyed at the quantum critical point along with a sudden change in the *f* character. The pressure variation of T_0 in the prototypical heavy fermion antiferromagnet $CeRh_2Si_2$ has been evaluated using the ^{29}Si NMR technique. A universal scaling behavior (Fig. 2) observed on the energy scale (Γ_0) of the local fluctuations in the entire pressure region demonstrates that the Kondo energy scale T_0 monotonically increases by applying pressure without a critical anomaly around the quantum critical pressure P_c~1.2 GPa of antiferromagnetism (the inset of Fig. 2). Our NMR result indicates that the progressive delocalization of the 4*f* electrons occurs across P_c, accompanied by the development of antiferromagnetic correlations among the 4*f* electrons, i.e., no local quantum criticality occurs in this material.

References

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[3] D. L. Cox *et al.*, J. Appl. Phys. **57**, 3166 (1985).

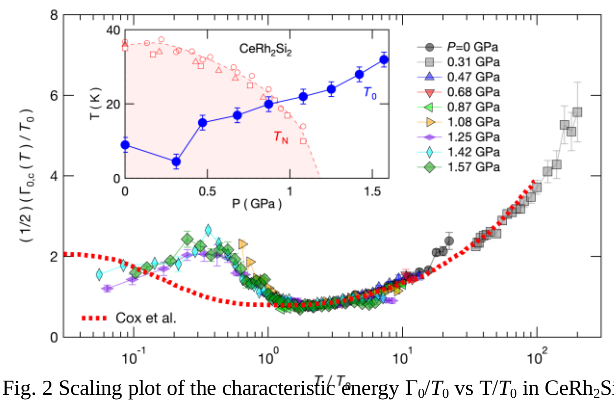

Fig. 2 Scaling plot of the characteristic energy Γ_0/T_0 vs T/T_0 in $CeRh_2Si_2$ under various pressures. The dotted curve represents the universal curve calculated for independently screened local moments based on a single Kondo impurity model [3] The inset shows the *T*-*P* phase diagram for $CeRh_2Si_2$.