

Summary of thesis: Superconducting multiphase and Magnetism in heavy-fermion Superconductor CeRh₂As₂

Shiki Ogata

In this thesis, we report the superconducting and magnetic properties of CeRh₂As₂ studied with nuclear magnetic resonance (NMR) and nuclear quadrupole resonance (NQR) measurements on an early-stage sample and a higher-quality sample. Most superconductors are described using the spin and orbital degrees of freedom. They are coupled through the fermionic anti-commutation relation, resulting in even-parity spin-singlet and odd-parity spin-triplet superconducting (SC) states. In locally noncentrosymmetric systems, however, the presence of sublattice degrees of freedom allows for an odd-parity spin-singlet SC state and a field-induced transition from an even- to odd-parity spin-singlet SC state. To date, CeRh₂As₂ [1] remains the only known candidate for such a superconducting multiphase.

CeRh₂As₂ is a heavy-fermion superconductor with a SC transition temperature $T_{SC} \sim 0.3$ K, which exhibits the SC multiphase under the c -axis field [2]. CeRh₂As₂ has global inversion symmetry, while the local inversion symmetry is broken at the Ce site. In addition to the SC multiphase, anomalies in the specific heat and thermal expansion at $T_0 \sim 0.4$ K have been reported [3], and we have reported an antiferromagnetic (AFM) order below $T_N \sim 0.25$ K [4], which attracted further interest in this compound.

Chapter 4: Parity Transition of Spin-Singlet Superconductivity Using Sublattice Degrees of Freedom [5]

We investigated the field dependence of the spin susceptibility and AFM order in the SC multiphase under c -axis fields up to 5 T. We revealed that the AFM order disappears above 4 T. Furthermore, the Knight shift exhibited a decrease at low fields, consistent with behavior expected for a spin-singlet state. However, almost no anomaly was observed at the phase boundary between low-field and high-field phases.

Chapter 5: Appearance of c -axis magnetic moment in odd-parity antiferromagnetic state in CeRh₂As₂ [6]

NMR measurements under the ab -plane field revealed that the linewidth broadening due to the internal field of the AFM state was significantly smaller compared to that under the c -axis field. We also observed NMR peak shifts induced by the internal field. These results indicate that the internal field at the As(2) site is aligned along the c -axis. We propose $\mathbf{Q} = \mathbf{0}$ A-type AFM order with c -axis moment as the most plausible magnetic structure.

Chapter 6: Incommensurate modulation with $Q = 0$ A-type Antiferromagnetic Order in CeRh₂As₂ [7]

We performed NQR measurements on a higher-quality sample where anomalies at T_0 became more pronounced. We revealed that, in the higher-quality sample, the AFM transition also became clearer, and T_N increased compared to the early-stage samples, showing that T_N almost coincided with T_{SC} . Furthermore, the NQR spectrum at the As(1) site broadened in the AFM state, suggesting two-dimensional incommensurate modulation.

Chapter 7: High-Field Odd-Parity Superconductivity in the Locally Noncentrosymmetric Superconductor CeRh₂As₂ [8]

For the higher-quality sample, we clarified the field dependence of the spin susceptibility and AFM order under c -axis fields up to 10 T. In the high-field phase, we identified a region where the Knight shift does not decrease, providing decisive evidence for a SC parity transition. Furthermore, the field dependence of the Knight shift revealed a coexistence region of even- and odd-parity phases. AFM vanished when T_0 disappeared, indicating that the order below T_0 is the origin of the AFM order.

Chapter 8: Conventional s -wave Superconductivity in LaRh₂As₂; the Analog without the $4f$ Electrons of CeRh₂As₂ [9]

We determined the SC symmetry of LaRh₂As₂ from T_1 measurements. LaRh₂As₂ is the analog of CeRh₂As₂ without the $4f$ electrons, exhibiting a T_{SC} close to that of CeRh₂As₂ but not a SC multiphase [10]. A pronounced coherence peak observed below T_{SC} confirms that LaRh₂As₂ is a conventional s -wave superconductor, which is unfavorable in CeRh₂As₂. The superconductivity in CeRh₂As₂ and LaRh₂As₂ can be considered qualitatively different, suggesting the importance of $4f$ electrons for the unique properties of CeRh₂As₂.

Overall, these results highlight the essential role of local inversion-symmetry breaking in realizing novel superconductivity and magnetism in CeRh₂As₂.

References

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