論文の内容の要旨

U-based itinerant ferromagnets investigated by field-angle-resolved measurements
(磁場角度回転実験によるウラン系遍歴強磁性体の研究)

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The itinerant ferromagnet URhGe is well known to be a ferromagnetic superconductor, in which ferromagnetism and superconductivity coexist. Ferromagnetism in URhGe is unique in that the Curie temperature can be tuned to zero by applying a magnetic field along the b axis, perpendicular to the easy c axis. In particular, this compound has attracted much interest because it shows a re-entrant superconductivity (RSC) in high magnetic field of $\mu_0 H \sim 12$ T, which is much higher than the Pauli limit (~ 1 T in URhGe), when a magnetic field is applied along the b axis. A first-order spin-reorientation transition occurs near RSC in URhGe, and the nature of the transition changes form a first-order transition to a second-order transition at a tricritical point (TCP) with increasing temperature. The position of TCP is under substantial debate in this system, because magnetic fluctuations near TCP associated with the moment reorientation are expected to play an essential role in RSC.

In order to determine the position of TCP, we have performed an experimental study of the wing structure (first-order transition plane) of URhGe in three-dimensional H_c-H_b-T phase diagram by means of dc magnetization, specific heat and magneto-caloric effect (MCE) measurements at low temperatures, where H_c and H_b are magnetic fields applied along the c and b axes of URhGe. Beginning at TCP in the three-dimensional phase diagram, the wing structure appears in a narrow field-angle range near the b axis. Owing to a strong magnetic anisotropy of URhGe, field-angle resolved in-situ measurements are needed to determine the position of TCP and to investigate the details of the wing structure. In order to perform field-angle resolved in-situ measurements, two-axis rotation device, which can work at low temperature, has been developed. The detail of the device is shown in Chapter 3. The main results of these measurements are summarized in Chapters 5 and 6. The theoretical and experimental backgrounds are introduced in Chapter 1.

Experimental methods used in the present work are described in Chapters 2. Dc magnetization and magnetic torque measurements have been performed by means of a capacitively-detected Faraday-force method. Specific heat has been measured by standard relaxation method, and MCE has been obtained by the change of the sample temperature with increasing-field and decreasing-field sweeps. After the explanation of the principle of the method, newly developed magnetometer and specific-heat cell are introduced. These cell have been developed to reduce torque contribution and misalignment of the magnetic-field-angle.

In Chapter 3, the details of the newly-developed two-axis rotation device are described. The orientation of the sample is precisely controlled within an accuracy of less than 0.01° using the device. The device consists of a piezo-stepper-driven goniometer (ϕ rotation) and a home-made tilting stage (θ rotation). The available angle ranges are $-3^\circ \leq \phi \leq 3^\circ$ and $-10^\circ \leq \theta \leq 10^\circ$, where the ϕ and θ axes are perpendicular to each other. The capacitive transducer and the specific heat cell can be mounted on a stage of the piezo-stepper-driven goniometer. The device allows us to perform high-precision angle resolved measurements. It is expected to greatly contribute to a clarification of strange phenomena in heavy electron systems, which usually have strong anisotropy. Chapter 4 deals with the performance evaluation of the two-axis rotation device by measuring angular dependences of a metamagnetic transition of $CeRu_2Si_2$ by means of dc magnetization measurements.

In Chapter 5, we have examined high-precision angle-resolved dc magnetization and magnetic torque studies on a single-crystalline sample of URhGe. This material is an orthorhombic Ising ferromagnet with the c axis being the magnetization easy axis, and this measurements have performed in order to investigate the phase diagram around the ferromagnetic (FM) spin-reorientation transition in a magnetic field near the b axis. We have clearly observed first-order transition in both the magnetization and the magnetic torque at low temperatures, and determined detailed profiles of the wing structure of the three-dimensional T-H_b-H_c phase diagram, where H_c and H_b are the field components along the c and the b axes, respectively. The positions of quantum wing critical points are at $\mu_0 H_c \sim \pm 1.1$ T and $\mu_0 H_b \sim 13.5$ T. Two second-order transition lines at the boundaries of the wing structure rapidly tend to approach with each other with increasing temperature up to ~ 3 K. Just at the zero conjugate field ($H_c = 0$), however, a signature of the first-order transition can still be seen in the field derivative of the magnetization at ~ 4 K, indicating that TCP locates in a rather high temperature region above 4 K. This feature of the wing plane structure is consistent with the theoretical expectation that three second-order transition lines merge tangentially at TCP.

In Chapter 6, angle-resolved specific heat and magneto-caloric effect measurements in URhGe have been performed, in order to decide the location of TCP and investigate the wing structure in other thermodynamic quantity measurement. A feature of the first order transition is observed in the temperature range up to 2-3 K by MCE measurements in a magnetic field applied along the b axis. The critical field of the transition obtained by MCE is almost the same as the ones decided by present magnetization and specific-heat measurements. The result of MCE measurements supports the conclusion that TCP locates above 4 K.