

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. Recently, it has become clear that these exotic behaviors for $5f$ -electron systems are different from those for $4f$ -electrons. This is because electrons with different spin and orbital character can coexist in $5f$ actinide systems, in contrast to the case of $4f$ electrons. 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 $4f$ and $5f$ compounds, including transuranium.

In this mid-term project, we also try to reclaim new fields such as topological and spintronic aspects in these compounds.

XY-type spin fluctuations in UPtGe [1]

The series of UTGe germanides have attracted considerable attention after the discovery of superconductivity in the ferromagnetic (FM) state of UCoGe and URhGe. Except for $T=$ Ru and Fe, the UTGe germanides exhibit static, long-range ordering of the U $5f$ spin moments. While UCoGe and URhGe are both simple ferromagnets with transition temperatures of 3 K and 9.5 K, the heavier transition elements ($T=$ Ni, Pd and Pt) introduce rather complex magnetic structure with relatively higher transition temperatures around 50 K. The most peculiar magnetic structure in the UTGe series appears in UPtGe. Below $T_N=50$ K, the compound exhibits an incommensurate helical (=cycloidal) order, where the U moments lie in the deformed hexagonal plane (Fig.1). In general, the helical magnetic structure has a periodicity incommensurate with the periodicity of the crystal lattice. The helical structure is thus naturally conflicted via the strong spin-orbit coupling, which connects the space and spin degrees of freedom. This implies that helical order is not a very likely ground state for actinide compounds, where the $5f$ electrons possess strong spin-orbit coupling. Up to now, UPtGe is the only actinide system known to exhibit helical structure.

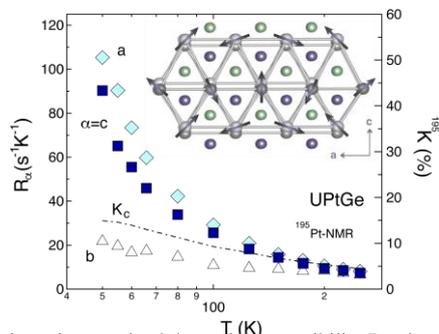


Fig. 1 Orientation-resolved dynamic susceptibility R_α along the three crystalline axis directions in UPtGe. (Inset) The projection onto the ac plane showing the cycloidal structure of the U moments in the ordered state.

In this study, we performed Pt NMR measurements on a single crystal of UPtGe. Knight shift measurement confirmed the isotropic character of the static spin susceptibilities in hexagonal-

like ac crystal planes of the EuAuGe-type crystal structure. The hyperfine coupling constants were also found to be isotropic in the planes, estimated to be 59 kOe/ μ_B . Nuclear relaxation rate measurement revealed the development of the antiferromagnetic spin fluctuations with XY character connected to the hexagonal-like plane below 200 K (Fig.1). The results present a clear contrast to the Ising anisotropy of the fluctuations in ferromagnetic superconductors UCoGe and URhGe.

Uniaxial magnetic anisotropy in UPtIn [2]

When Ge is substituted by In, another intermetallic compound UPtIn is formed. It crystallizes in hexagonal ZrNiAl-type structure. UPtIn is known as an antiferromagnet. The magnetic transition temperature (T_N) had not been well established. An arc-melted sample orders at 22 K, while a sample obtained through solid state reaction shows significantly lower $T_N = 15$ K. Such large sample dependence is most likely due to the difficulty in sample preparation: one must melt indium which has extremely low melting point (157 °C) and platinum (1768 °C) at the same time. We tried to synthesize UPtIn by indium flux method. In this technique, uranium and platinum are put and dissolved in molten indium at relatively low temperature in inert atmosphere. With slowly cooling down the melt, we succeeded to obtain UPtIn crystals. The sample was characterized by single crystal X-ray diffraction and electron microprobe analyses, confirming atomic arrangements and homogeneous composition. Using the single crystal, we reinvestigate physical properties. Figure 2 shows the temperature dependence of magnetic susceptibility. Susceptibility values with magnetic field along the c -axis are almost 10 times larger than those with perpendicular field, corresponding to uniaxial magnetic anisotropy, in contrast to XY-type in UPtGe. This result shows substitution of one constituent element modifies not only the crystal structure but the magnetic anisotropy. We also found that T_N of single crystal is even lower than the reported values. We have not fully understood the mechanism of diversity of transition temperature. The sensitivity of physical quantities on impurity or substitution, however, demonstrates importance of pure specimens to reveal intrinsic properties.

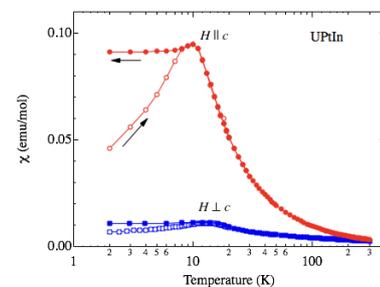


Fig. 2 Temperature dependence of magnetic susceptibility of UPtIn.

References

- [1] [Y. Tokunaga et al., Phys. Rev. B98, 014425 \(2018\).](#)
- [2] [Y. Matsumoto et al., J. Phys. Soc. Jpn. 87, 024706 \(2018\).](#)