Research Group for Actinide Materials Science

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5f electrons in actinide compounds play essential roles in various phase transitions in actinide compounds. The electronic states can be modified by the chemical or physical environment around these electrons. It is therefore interesting to investigate new materials under various conditions such as pressure, magnetic field or low temperature to find new phenomena. The purification of a known compound also provides new insight particularly for phenomena occurring at low temperatures, where impurity disorder can deeply disturb and hence hide the intrinsic behavior. Here we report recent results on a new uranium compound and anomalous ferromagnetic critical behavior in the uranium compounds.

New uranium compounds grown from metal flux

A series of actinide compounds with the tetragonal $HoCoGa_5$-type structure have been extensively studied because of the variety of physical phenomena, including unconventional superconductivity and magnetic/multipole orderings. Among them $URhGa_5$ is known as a nonmagnetic metal, in contrast to the unconventional superconductor $PuRhGa_5$ and $NpRhGa_5$ showing multiple magnetic orderings. We have successfully grown a new uranium compound $URhIn_5$, which is isostructural and isoelectronic to $URhGa_5$ but has a significantly larger unit cell volume [1]. Physical properties measured on a bulk single crystal, as well as microscopic investigation using ^{115}In-NMR [2], demonstrated an antiferromagnetic ground state. This result directly shows that a modification of *5f* states from itinerant to magnetic characteristics takes place in $URhIn_5$. It is naturally expected that the application of pressure would drive $URhIn_5$ back to a nonmagnetic state as in $URhGa_5$. However, even under the hydrostatic pressure of 4 GPa, the antiferromagnetism is stabilized as demonstrated by the increase of the transition temperature under pressure.

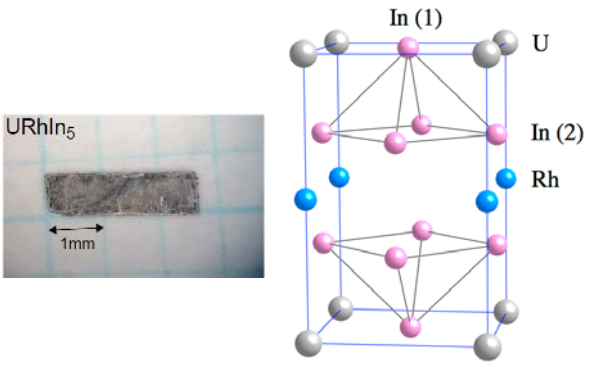

Fig.1 A single crystal of $URhIn_5$ grown from the indium flux, and its crystal structure determined from the single-crystal X-ray diffraction.

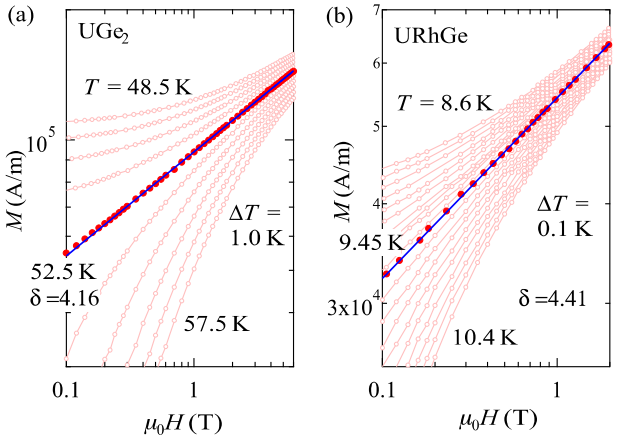

Fig.2 Examples of experimental data used to determine critical exponents. From the magnetization as a function of applied magnetic field, one of the critical exponents δ has been determined.

Unconventional critical scaling in uranium ferromagnet

Ferromagnetism is observed in several uranium compounds. Among them UGe_2, URhGe and UCoGe are known as ferromagnets showing superconductivity at lower temperatures. Superconductivity carried by the ferromagnetic electrons is only observed in uranium compounds. This fact strongly suggests that ferromagnetism in uranium compounds has a peculiar feature which could induce superconductivity. We have investigated the ferromagnetic ordering in these compounds by characterizing the critical phenomena around the ferromagnetic transition temperature. Note that the critical phenomena are thermodynamic properties characterizing the global features of phase transition, and therefore are insensitive to the details of microscopic difference of the material in question. For example, the critical exponents which characterize the critical phenomena are exactly the same for the liquid-gas transition and uniaxial ferromagnetism. For ferromagnetic transition in general, theory successfully predicts critical exponents, in agreement with experiments. For UGe_2 and URhGe, however, we found that the critical exponents determined experimentally differ significantly from the theoretical predictions [3]. We looked for the reasons of the difference by considering the characteristic feature for uranium compounds, including the itinerant *5f* states, peculiarity of the crystal structure in these compounds, possible long-range interaction between magnetic moments, classical dipole-dipole interactions, etc. Although the satisfactory explanation has not been made, the present work would stimulates the further theoretical investigation on ferromagnetism and its coexistence with superconductivity.

References

[1] Y. Matsumoto *et al.*, Phys. Rev. B **88**, 045120 (2013).
[2] H. Sakai *et al.*, Phys. Rev. B **88**, 045123 (2013).
[3] N. Tateiwa *et al.*, Phys. Rev. B **89**, 064420 (2014).