Investigation of the Quantum Criticality of URu_2Si_2 and its Novel Emergent Phases around 40 T: a High Field ^{29}Si-NMR Study (Following up the Project ID: P01917)

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Introduction

The so-called "hidden-order" (HO) phase transition in the heavy-fermion compound URu_2Si_2, at transition temperature T_O = 17.5 K, has posed a long-standing mystery. URu_2Si_2 is also a very attractive material displaying intriguing T-H phase diagrams (Fig. 1(b)) [1, 2] determined by the electronic transport measurements such as resistivity and Hall effect. In particular, an anomaly in the Hall resistivity around H^*~22 T has been reported within the HO phase [1]. It is also reported that the critical field of the HO phase is about H_c = 35 T by means of resistivity measurements [2]. High field NMR is a very suitable microscopic technique to investigate these anomalies in URu_2Si_2. The single crystals studied in this project were enriched with 99.8% of ^{29}Si isotope, a very suitable nucleus (I = 1/2) for NMR measurements. It should be noted that the natural abundance of ^{29}Si is only 4.7 %, which is too diluted for high field measurements.

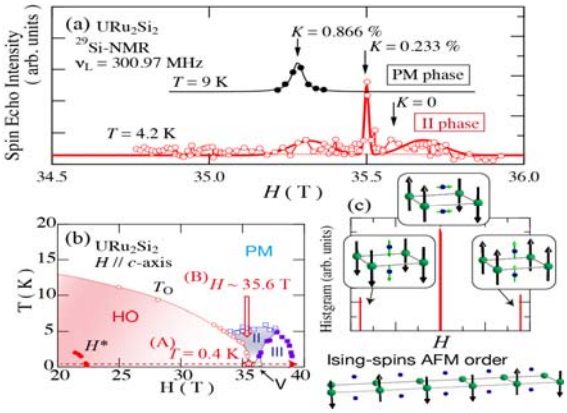

Fig. 1 (a) ^{29}Si-NMR spectrum in the PM and II phases, (b) T-H phase diagram for URu_2Si_2, and (c) Schematic spin picture in the II phase.

Experimental

The sample quality had been verified by means of resistivity and low field NMR measurements. During our last high field experiments at Cell 15, the measurements of NMR shift with applied magnetic fields up to ~ 40 T were performed. The ^{29}Si-NMR spectra were obtained at constant T = 4.2 K, in the magnetic phase just above the HO phase.

Results and Discussion

It is worth briefly mentioning few striking NMR results: the low-T ^{29}Si-NMR shift (K) anomaly around H^* and the critical increase of K towards H_c ~ 35.6 T. Both results must be related to crucial changes in the Fermi surface of URu_2Si_2. Another remarkable result is the first observation of the ^{29}Si-NMR spectrum in the high-field paramagnetic (PM) phase at 40 T as well as the complex ^{29}Si-NMR spectrum in the magnetic phase II displayed in Fig. 1(a). This spectral shape can be understood by an antiferromagnetic ordering of *Ising*-type localized spin arrays, as illustrated in Fig. 1(c). The ordered moment of □ 0.6 μ_B/U in phase II is estimated by considering the hyperfine coupling constant A^c_{hf} = 3.4 kOe/μ_B obtained in the PM and HO phases.

Conclusions

Our high field NMR results provide the first microscopic evidence of the change in the magnetic susceptibility around the anomaly observed at H^*~ 22 T which, in turn, could not be unveiled by previous transport measurements. Furthermore, based on our NMR data, the transition between the hidden order and the novel field-induced phase at H_c ~ 35.6 T is found to be of first order. The U localized moments with *Ising*-type character suddenly emerge in the antiferromagnetic phase II from the non-magnetic itinerant HO state and this behavior may find some connection with a recent proposed theoretical model [3].

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References

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