μSR study of heavy fermion superconductor URu_2Si_2

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Despite intensive studies for more than two decades, the order parameter of the mysterious phase transition at T_0 = 17.5 K[1)] in URu_2Si_2 has not been identified yet, and thus the ordered phase is referred to as the hidden order (HO) phase.

The symmetry of the HO phase is crucial information for the identification of its order parameter. Recent Shubnikov-de Haas experiments have revealed that the Fermi surfaces in the HO phase are very similar to those of the pressure induced antiferromagnetic phase.[2)] This confirms that translational symmetry is broken in the HO phase, and the ordering vector is $Q_{HO} = (1, 0, 0)$. In addition, in the HO state, NMR and magnetic torque experiments have shown that the four-fold rotational symmetry in the (001) plane is broken.[3,4)] On the other hand, the time-reversal symmetry (TRS) is still a controversial issue, since we can find two types of very recent theoretical models for the HO transition: some of the theoretical models assume that the TRS is conserved in the HO phase,[5)] while the others assume that TRS is broken.[6)] Therefore, although the previous NMR and μSR studies have reported the development of tiny internal magnetic fields below T_0[7,8)] and indicate the breaking of the TRS in the HO phase, further characterization of the internal magnetic field in the HO phase is required. In the present study, we performed zero-field (ZF) and longitudinal-field (LF) μSR experiments on a single crystal of URu_2Si_2 in order to characterize the internal magnetic fields in the HO state.

The inset of Fig. 1 shows ZF-μSR spectra at 11 and 19.5 K, which are below and above T_0. The ZF-spectra were well fitted by a single exponential function

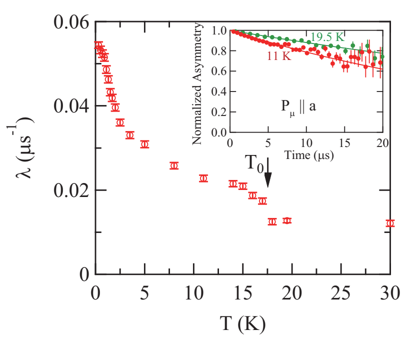

Fig. 1. Temperature dependence of the ZF-relaxation rate. The inset shows the ZF-μSR spectra measured at 11 and 19.5 K.

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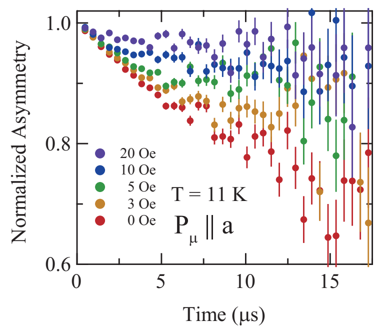

Fig. 2. The LF-μSR spectra at 11 K under several longitudinal fields.

$A_0\exp(-\lambda_{ZF}t)$ over the temperature range presently investigated. We observed an enhancement of λ_{ZF} in the HO phase, which reflects a development of the TRS breaking magnetic field. Figure 1 exhibits the temperature dependence of λ_{ZF}, and a sharp increase is clearly observed at T_0. λ_{ZF} shows a saturated feature around 10 K, but it exhibits an additional increase with further decreasing temperature and keeps increasing down to the lowest temperature.

In order to investigate the dynamics of the internal magnetic field in the HO phase, we performed LF-field experiments where LF was applied parallel to the a-axis. Figure 2 shows the LF-μSR spectra measured at 11 K. The long tails of relaxation spectra are strongly affected by applying tiny LFs. This is a characteristic feature in the presence of a static field distribution at muon sites. In this case, the exponential relaxation in the ZF experiments reflects the presence of a Lorentzian field distribution at muon sites. Since the relaxation rate under LFs is a measure of transverse components of field fluctuations at muon sites, the observed decoupling behavior implies the absence of measurable field fluctuations along both the a and c directions. Hence, we conclude that measurable magnetic fluctuations do not exist along any directions at muon sites, and the internal magnetic field developed in the HO phase is static on the time scale of μSR.

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