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Hidden Order in URu_2Si_2 Studied by Single-Crystal NMR

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The still unclarified hidden order (HO) phase below T_0=17.5 K in URu_2Si_2 has been investigated by ^{29}Si (I=1/2) NMR on two single crystals under ambient P.

In order to describe the tiny-moment antiferromagnetism (AF) under ambient P, the model of the "Smal-Moment AF" (SMAF) has been proposed previously, which interprets the ambient-P tiny-moment AF in terms of spatially homogeneous AF with $\mu_{\rm SMAF}$=0.02-0.04 $\mu_{\rm B}$//[001] and Q_0=[001] over the entire sample. The ^{29}Si NMR FFT spectra for $H_{\rm ext}$//c-axis at T=4.5 K covering a wide frequency range has revealed no splitting of the line expected for the SMAF on the basis of a scaling from the P-stabilized Q_0 AF. Our results can definitely exclude the SMAF model to explain the ambient-P tiny-moment AF, but support the inhomogeneous model, in which the ambient P tiny-moment AF occurs spatially inhomogeneously only in a very tiny part (of the order of 0.6 %) and the HO occurs in the remaining majority of the sample.

In the HO phase, the ^{29}Si NMR linewidth $\Delta H_{1/2,p}$ for $H_{\rm ext}$//p-axis (p=a, c) can include the additional contribution $\delta H_{{\rm add},p}$, due to the internal field from the HO, over the inhomogeneous width αM_p that is proportional to the bulk magnetization M_p ($\Delta H_{1/2,p}$=$\Delta H_{{\rm add},p}$+αM_p). For $H_{\rm ext}$//c-axis, $\Delta H_{{\rm add},c}$ appears below T_0, has a peak around 16.5 K, decreases gradually and then disappears almost completely around 14 K. The nuclear spin transverse relaxation rate $1/T_{2c}$ also shows a peculiar T-dependence with a peak around 16.5 K. Such an anomaly, however, is not observed in the closely related nuclear spin longitudinal relaxation rate $1/T_{1a}$, which points to the existence of the very slow internal-field fluctuations just below T_0. In the presentation, we discuss that these anomalous behaviors of $\Delta H_{1/2,c}$ and $1/T_{2c}$ can be explained consistently in terms of the short-range AF order induced in the time-reversal-symmetry-breaking multipole order under remaining residual strains most probably caused in connection with stacking-faults in the crystal.

The finite $\Delta H_{{\rm add},a}$ for ^{29}Si (I=1/2) even as $H_{\rm ext}\rightarrow$0 for $H_{\rm ext}$//a-axis around 14 K, where the above short-range AF disappears, also indicates that the time-reversal-symmetry is broken at T_0. We will show that the octupole T_z^β or T_{xyz} order in the singlet ground-state level-scheme is the most likely scenario for the HO in URu_2Si_2.