Microscopic characterization of "nematic" precursor state of unconventional superconductivity in URu_2Si_2

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In the superconducting state, two electrons form superconducting pairs. For the formation of pair electrons, an attractive interaction between electrons is necessary. In conventional superconductors, the origin of the attractive interaction is lattice vibration. In contrast, magnetic fluctuation is considered to be the origin in actinide superconducting compounds. Since high superconducting transition temperature T_c can be expected for a magnetic-fluctuation induced superconductor, it is important to clarify the mechanism of it.

The heavy fermion superconductor URu_2Si_2 undergoes a second order phase transition at $T_0 = 17.5$ K. Since the order parameter of the transition has not ever been clearly identified, such order has been termed "hidden order". As the superconducting transition occurs at lower T_c=1.5 K, the hidden order is precursor state of superconductivity. Owing to the tetragonal crystal structure of URu_2Si_2 (space group *I/4mmm*), the physical properties of the paramagnetic state of this compound exhibit 4-fold rotational symmetry in the basal: (001) plane. In recent in-plane anisotropy measurements of the static magnetic susceptibility, the 4-fold symmetry was reported to be spontaneously broken below T_0, and a 2-fold rotationally symmetric state was found to appear [1]. Since the symmetry breaking was observed without identifying its microscopic origin, this ordered phase is termed "nematic" for the moment; it has been interpreted with several models.

As a result of domain formation, the measurable 2-fold symmetric susceptibility depends strongly on sample size and can only be detected in very small (nearly mono domain) samples [1]. On the other hand, NMR results to be presented here do not depend on sample and domain size, since NMR measurements probe the microscopic state at each nuclear site individually. The present NMR results are consistent with domain formation. While domains render the susceptibility and the NMR shift isotropic in the basal plane, in this note we show that a detailed analysis of Si NMR linewidth data offers a quantitative measure of the 2-fold susceptibility effect. The intrinsic (mono–domain) 2-fold susceptibility in a macroscopic single crystal sample has been precisely determined in the present study.

The low natural abundance (4.7%) of the NMR isotope ^{29}Si (I=1/2, gyromagnetic ratio: 845.77 Hz/Oe) has prevented highly accurate Si NMR measurements in URu_2Si_2 up to now. For the present study a single crystal sample has been prepared with the ^{29}Si isotope enriched to 53%, improving the NMR sensitivity by a factor 11. This makes it possible for the first time to resolve the in-plane magnetic anisotropy by means of NMR measurements.

Figure 1 shows the angle θ dependence of linewidth $L(\theta)$. In the paramagnetic state above T_0, $L(\theta)$ shows a simple sinusoidal curve, on the other hands, in the ordered state below T_0, $L(\theta)$ shows a particular peak minimum at 45 degrees which indicates a development of nematicity as decreasing temperature [2]. Analysis of our linewidth data leads to the estimate 0.4% for the 2-fold intrinsic (mono–domain) susceptibility anisotropy in the basal plane. This result is consistent with recent thermal expansion measurements under uniaxial pressure [3]. It is remarkable that the unconventional superconductivity occurs in this nematic precursor state, thus nematically magnetic fluctuation is considered to induce the unconventional superconducting state.

A future new superconductor with higher T_c is considered to be realized in magnetic fluctuation mediated superconducting system, since T_c of phonon-mediated superconductors already has reached its peak. If a new superconductor with room temperature T_c is found, it will be quite useful for an improvement of the energy efficiency.

We are going to investigate actinide compounds to clarify the mechanism of superconductivity in detail.

References

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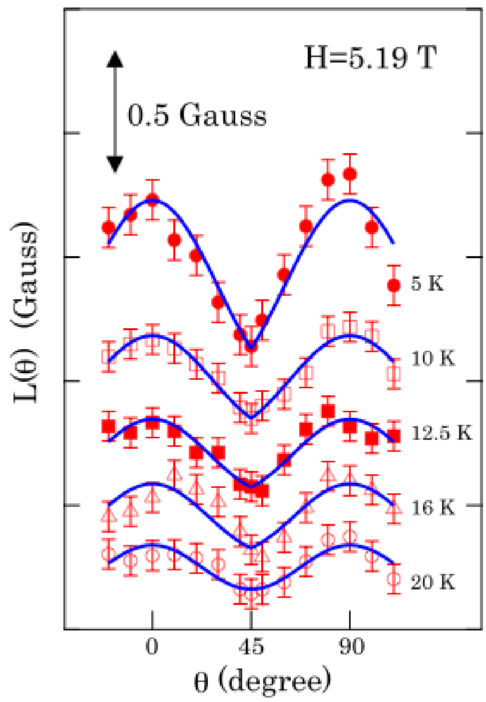

Fig. 1 Angle θ dependence of ^{29}Si-NMR spectra linewidth $L(\theta)$ in URu_2Si_2 at applied field H=5.9 T in the (001) plane. The angle θ is angle between H and the [110] crystal direction. Below T_0=17.5 K, a particular peak minimum appears at θ=45 degrees, which becomes prominent at low temperatures. The appearance of the peak minimum indicates the nematic hidden ordering.