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Ultrasonic investigation of quadrupolar effect in $PrPb_3$

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$PrPb_3$ is well known as typical examples showing an antiferro-quadrupolar ordering(AFQ) and Γ_3 ground state systems[1]. The Hund's ground multiplet $^3H_4$ of Pr^{3+} in a cubic-crystal-electric-field(CEF) splits into a singlet Γ_1, a doublet Γ_3 and two triplet Γ_4 and Γ_5 above the ground state. $PrPb_3$ is characterized as a system with the Γ_3 ground state and CEF level scheme $\Gamma_3 - \Gamma_4(14.9\ K) - \Gamma_5(28.3\ K) - \Gamma_1(35.3\ K)$[2]. In the CEF splitting energy, low temperature properties of $PrPb_3$ are dominated by the ground state doublet Γ_3 with SU(2) symmetry, which possesses three quantum degrees of freedom, two electric quadrupoles ($O_2{}^0 = (2J_z{}^2 - J_x{}^2 - J_y{}^2)/\sqrt{3}$ and $O_2{}^2 = J_x{}^2 - J_y{}^2$) and one magnetic octupole ($T_{xyz} = \overline{J_x J_y J_z}$). Here, the bar means the sum of cyclic permutations on x, y, and z. The measurement of an elastic constant $(C_{11} - C_{12})/2$ is a suitable probe for observing the quadrupolar susceptibility for $O_2{}^2$ of the non-Kramers Γ_3 doublet. The recent experiments using neutron scattering show that incommensurate structure of field induced magnetic moments appear below quadrupole transition temperature T_Q=(0.4K)[3].

The $(C_{11} - C_{12})/2$ in zero magnetic field in Fig 1 decreases with decreasing temperature from 120 K and exhibits a minimum about 7 K. Below 7 K, $(C_{11} - C_{12})/2$ increases slightly with lowering temperature and shows maximum at 5 K. Then, $(C_{11} - C_{12})/2$ shows a softning obeying the Curie-type behavior proportional to the reciprocal temperature $1/T$ down to T_Q. The increasing in $(C_{11} - C_{12})/2$ below T_Q provides the quadrupole ordering the $O_2{}^2$ and $O_2{}^0$ of the non-Kramers Γ_3 doublet in $PrPb_3$.

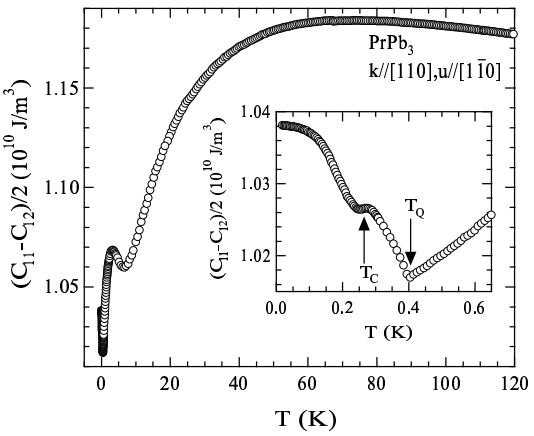

Figure 1: The temperature dependence of the elastic constant $(C_{11} - C_{12})/2$ in $PrPb_3$

[1] P. Morin et al., J. Magn. Magn. Mater 30 (1982) 257
[2] T. Tayama et al., J. Phys. Soc. Jpn. 70 (2001) 248-258
[3] T. Onimaru et al., Phys. Rev. Lett. 94, 197201 (2005)