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Ultrasonic study of crystal field, off-center rattling and superconductivity in clathrate $PrOs_4Sb_{12}$

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We measured the elastic constants of clathrate $PrOs_4Sb_{12}$. The softening of the $(C_{11}-C_{12})/2$ and C_{44} reveals quadrupolar fluctuation of the CEF state [1]. The $(C_{11} - C_{12})/2$ in magnetic fields along [110] at 950 mK shows a minimum around 8 T, which is well described by one-ion quadrupole susceptibility indicating a level crossing of the Γ_1 singlet and $\Gamma_4^{(2)}$ triplet around 8T. Furthermore, ultrasonic dispersion around 20-30 K has been observed in all elastic constants of C_{11}, $(C_{11} - C_{12})/2$ and $C_L = (C_{11} + C_{12} + 2C_{44})/2$ including Γ_{23} symmetry, while in the case of C_{44} with Γ_5 symmetry ultrasonic dispersion is absent. This is contrast to the results of $Ce_3Pd_{20}Ge_6$ [2] and $La_3Pd_{20}Ge_6$ that reveals ultrasonic dispersion only in C_{44} with Γ_5 symmetry. This thermal activated type dispersion is attributed to the off-center rattling of Pr ion with Γ_{23} symmetry along [100] in cage consisting of Sb icosahedron. At low temperatures a new type of degrees of freedom due to off-center tunneling ion in cage may play an important role in enhancement of the softening of $(C_{11} - C_{12})/2$ below 3 K down to T_C and in heavy fermion behavior and unconventional superconductivity in $PrOs_4Sb_{12}$.
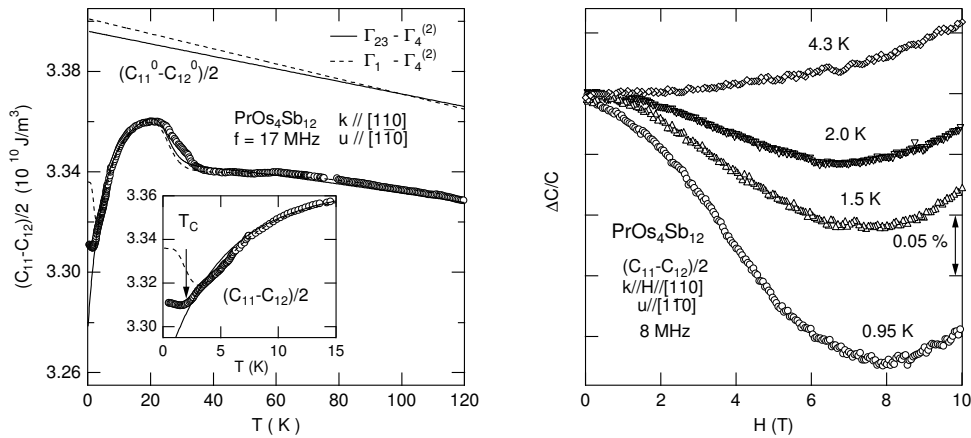

Figure 1: Temperature dependence (left) and magnetic field dependence (right) applied fields along the [110] direction of $(C_{11} - C_{12})/2$.

[1] T. Goto, Y. Nemoto, K. Sakai, T. Yanagisawa, M. Akatsu, T. Yanagisawa, H. Hazama, K. Onuki, H. Sugawara, and H. Sato, Phys. Rev. B **69** (2004) 180511(R).
[2] Y. Nemoto, T. Yamaguchi, T. Horino, M. Akatsu, T. Yanagisawa, T. Goto, O. Suzuki, A. Dönni, and T. Komatsubara, Phys. Rev. B **68** (2003) 184109(R).