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Specific heat anomaly in the heavy fermion superconductor $PrOs_4Sb_{12}$

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After the discovery of superconductivity in $PrOs_4Sb_{12}$ [1], which is to date the only known Pr-based heavy-fermion superconductor, much of experimental evidence have been reported suggesting that the superconductivity is unconventional [2,3]. One important aspect is the possibility of the existence of multiphase superconducting (SC) phases suggested from anomalies in specific heat and thermal conductivity measurements [4,5].

Our measurements on several samples suggest that the structure in specific heat around the SC transition exhibits noticeable sample dependence; some samples show apparently double transition structure but others show a jump followed by a lower-temperature kink structure. It does not seem that these structures are indicative of transitions between multiple SC phases. In the constructed magnetic-field-vs-temperature phase diagram, the temperature of the two anomalies ($T_{c1} > T_{c2}$) decreases with increasing magnetic field in a way forming two parallel lines; in contrast to the phase diagram obtained from the thermalconductivity measurement [5]. Furthermore, the magnetic anisotropies of T_{c1} and T_{c2} have the same characteristic behavior. AC magnetic susceptibility for a powered sample shows clear increase in the magnetic shielding around T_{c2}, that is less visible for unpowdered samples. These observations suggest that the double transition structure is rather attributable to the distribution of the superconducting transition temperature in the sample.

The thermodynamical character of the heavy-fermion superconductivity in $PrOs_4Sb_{12}$ is difficult to be investigated quantitatively because of the existence of the low-energy (8 K) crystalline electric field (CEF) excitations of Pr ions. Furthermore, due to this background anomaly, the precise value of the Sommerfeld electronic specific heat coefficient γ had been difficult to be estimated. In order to overcome these difficulties, we have obtained the difference in the specific heat between the SC and normal states $\Delta C/T = C_{SC}/T - C_N/T$, by phenomenologically estimating the normal-state specific heat $C_N(T)$ in $H = 0$. The results show marked deviation from ordinary BCS model. The results provide evidence for extremely strong-coupling superconductivity in $PrOs_4Sb_{12}$. Furthermore, we found an anomalous temperature dependence in $\Delta C/T$. This finding may suggest that the low-energy quasi-particle excitations has anomalous energy dependence probably caused by either the CEF excitations or off-center local excitations of Pr ions [6].

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