Comment on “Pronounced Enhancement of the Lower Critical Field and Critical Current Deep in the Superconducting State of PrOs$_4$Sb$_{12}$”

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(Dated: January 18, 2010)

PACS numbers: 74.25.Ha, 71.27.+a, 74.25.Op, 76.75.+i

Cichorek et al. [1] reported enhancements of the lower critical field $H_{c1}(T)$ and critical current $I_c(T)$ in superconducting PrOs$_4$Sb$_{12}$ below a transition temperature $T_{c3} \approx 0.6$ K, and speculated that this reflects a transition between superconducting phases. Features have been observed near $T_{c3}$ in other properties, but not in the specific heat. We report muon spin rotation ($\mu$SR) measurements of the penetration depth $\lambda$ in the vortex state of PrOs$_4$Sb$_{12}$ near $H_{c1}$, that to high accuracy exhibit no anomaly $T_{c3}$ and therefore cast doubt on the putative phase transition.

In a Type-II superconductor $H_{c1} = \Phi_0/(4\pi \kappa^2 c^2)$, $c \approx 0.5$, where $\Phi_0$ is the flux quantum and $\kappa$ is the Ginzburg-Landau parameter [2]. Modification of the superfluid density $\rho_s$ by a phase transition should affect both $\lambda = (mc^2/4\pi \kappa^2 \rho_s)^{1/2}$ and $H_{c1}$. A feature observed near $T_{c3}$ in rf inductive measurements of $\lambda$ [3] is too small to account for the observed enhancement of $H_{c1}$ [1].

In the transverse-field $\mu$SR technique the spectrum of muon precession frequencies gives the local-field distribution function, which depends on $\lambda$ in the vortex state [2]. $\mu$SR experiments were carried out at the ISIS $\mu$SR facility on a polycrystalline sample of PrOs$_4$Sb$_{12}$. Strong de Haas-van Alphen signals obtained from similarly-prepared crystals [4] attest to their high quality. Data were taken in low applied fields $H = 25$ and 40 Oe, the former corresponding to an internal field $H' \approx 32$ Oe at $H' = H_{c1}(T)$ after demagnetization correction. This is close to the estimated unenhanced value of $H_{c1}(0)$ [1], so that in the absence of enhancement $H'$ should be $H_{c1}$.

The data are well fit by the Gaussian relaxation function $G(t) = \exp(-t^2/2 \sigma^2)$, $\cos(\omega_{\mu} t + \theta)$. Figure 1 gives the average muon spin precession frequency $\omega_{\mu}(T)$ and relaxation rate $\sigma(T)$ at 25 and 40 Oe. There is no discernible anomaly at $T_{c3}$, and no evidence that $H' < H_{c1}$. Similar results are found at higher fields [5].

The rms width $\delta B_{\text{rms}}$ of the field distribution in the vortex state is estimated by $\sigma/\gamma_\mu$, where $\gamma_\mu$ is the muon gyromagnetic ratio. In the London model $\delta B_{\text{rms}} = 0.00371 \Phi_0^2/\lambda^3$ [2], i.e., $H_{c1}$ and $\delta B_{\text{rms}}$ are (essentially) proportional to $\Phi_0/\lambda^2$ and therefore to each other: $H_{c1}/\delta B_{\text{rms}} = 1.31(\ln \kappa + c) \approx 5.0$ in PrOs$_4$Sb$_{12}$. Thus a $\sim 50\%$ enhancement of $H_{c1}(0)$ [1] implies a similar enhancement of $\sigma(0)$ contrary to our results. From $\sigma(0)$ we estimate $H_{c1}(0) \approx 50$ Oe, of the order of the observed value, so that other broadening mechanisms, such as vortex-lattice disorder or a distribution of demagnetizing fields, are unlikely to dominate the muon relaxation.

These results and the absence of a specific heat anomaly at $T_{c3}$ are evidence against a phase transition associated with the enhancement of $H_{c1}$ at low temperatures in PrOs$_4$Sb$_{12}$. The enhanced critical current suggests that flux pinning effects, which generally become stronger at low temperatures, are involved.

Work supported by the U.S. NSF, Grant no. 0422674 (Riverside), and a Grant-in-Aid for Scientific Research on Priority Areas (19052003) (Tokyo).
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