Comment on "Low Temperature Fluctuations of Vortices in Layered Superconductors"

In a recent Letter [1], Song *et al.* presented data on the ^{205}Tl NMR linewidth in partly oriented $Tl_2Ba_2Ca_2Cu_3O_{10}$ powders. In the model used [2,3], the variance of the field distribution is reduced by the motion of pancake vortices around their equilibrium positions. The model seems only valid if the mean square deviation from equilibrium is small. Using the 3D Lindemann melting criterion this would imply that T/T_c has to be lower than 0.4. Numerical simulation of vortex motion in a single and a multilayer system with vortices coupled only magnetically [4] showed a similar line narrowing. Because in these simulations the line profiles were directly calculated via the relevant correlation function, they do not show whether vortex fluctuation or diffusion is responsible for the line narrowing (although vortex diffusion was suggested to dominate).

Here we will calculate the diffusion constant D directly from the experimental line profile and see how it compares with the numerical simulation of D [5]. The line profile for a time dependent field is given by $F(\omega) = \int dt\, G(t) \exp(-i\omega t)$ [6]. We assume that $G(t)$ is related to the correlation time for vortex motion τ via

$$G(t) \approx \exp(i\omega_0 t) \exp\{-\omega_p^2 \tau^2 [\exp(-t/\tau) - 1 + t/\tau]\},$$

and that D is of the order of $D \approx a_0^2/2\tau$; ω_p is a measure for the linewidth in the absence of vortex motion, $\omega_0/2\pi$ denotes the nuclear precession frequency, and a_0 the flux lattice constant. In Fig. 1 we show D as a function of T in a field of 4.7 T for $\mathbf{B} \| \mathbf{c}$ [7]. D varies with T from 10^{-10} around 20 K to 10^{-8} around 80 K. Normal state linewidths (FWHH) were fitted by $103 - 7.66 \times 10^{-2} T$ (kHz). For the low temperature value we used 390 kHz (as measured at 0.4 K). The precise values of these parameters are important especially below 20 K or above 80 K [8]. In the same figure we show the simulated D values for $\mathbf{B} \| \mathbf{c}$ without pinning for a field of 1 T (by extrapolation of the simulations we estimate D in 4.7 T to be a factor of 2–3 lower). If weak pinning is included the diffusion coefficient might increase by about a factor of 3 [4]. As can be seen from Fig. 1, within the crude approximations made here, simulated and measured values agree rather well. Also in muon spin rotation there are indications of vortex diffusion [9].

In conclusion, numerical simulations strongly suggest that apart from vortex vibration, vortex diffusion plays an important role in the line narrowing in highly anisotropic superconductors like the Tl-based high T_c's.

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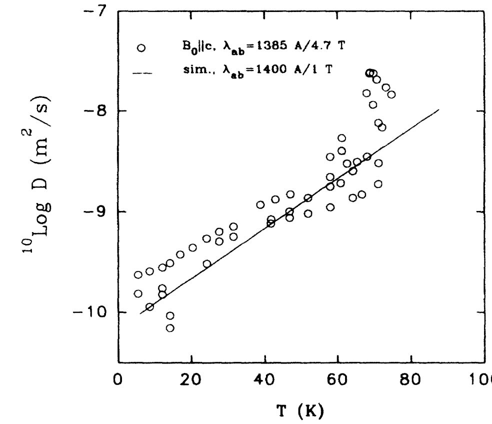

FIG. 1. The T dependence of D in $Tl_2Ba_2Ca_2Cu_2O_8$.

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[5] In $Tl_2Ba_2Ca_2Cu_3O_{10}$ the number of data points is rather limited. In the analogous system $Tl_2Ba_2Ca_2Cu_2O_8$ more dense data sets are available, both on oriented powders from the Stuttgart group [N. Winzek *et al.*, Physica (Amsterdam) **205C**, 45 (1993); M. Mehring *et al.*, Solid State Commun. **75**, 753 (1990)] and fully aligned single crystals from the Leiden group [J. C. Jol *et al.*, Physica (Amsterdam) **175C**, 12 (1991); J. T. Moonen *et al.*, Physica (Amsterdam) **185-189C**, 1891 (1991); H. B. Brom *et al.*, Appl. Magn. Res. **3**, 597 (1992)].
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[7] As was shown by the Stuttgart and Leiden groups the Tl line profile in $Tl_2Ba_2Ca_2Cu_2O_8$ is complicated by the presence of a few percent of Tl on the Ca site. This "impurity" line has a strongly T dependent Knight shift, and merges with the main line below 40 K for $\mathbf{B} \|$ the c axis. For that reason our data for $\mathbf{B} \| \mathbf{c}$ are considerably less accurate than for B aligned within a few degrees with the (a,b) plane; the T dependences are similar.
[8] If we use the two-fluid expression for λ and take the linewidth $2.36\sqrt{M_2}$, the resultant low temperature linewidth of 380 kHz for the flux lattice corresponds to $\lambda = 1385$ Å. The coherence length ξ, which determines the extent of the normal cores, and the presence of disorder suppress the tails in the line profile. The line profile will be more Gaussian and M_2 will be reduced (disorder might also lead to an additional line broadening).
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