Comment on "Is the Nonlinear Meissner Effect Unobservable?"

In a recent Letter [1] by Li, Hirschfeld, and Wölfle (LHW) on nonlocal effects in unconventional superconductors, it was suggested that these effects might explain the null result for the nonlinear Meissner effect (NLME) in our experiments [2,3] on optimally doped $YBa_2Cu_3O_{6.95}$ (YBCO) single crystals for which an appreciable signal is predicted by theory [4,5].

We have no objection to the main part of the LHW Letter, which deals with a detailed calculation of the nonlocal effects [6]. However, the remarks made about our experimental results do not directly follow from these detailed calculations but are critically dependent on a qualitative argument which fails to work for YBCO.

The qualitative argument relies on treating YBCO as a "weakly 3D" system. This leads LHW to the conclusion that nonlocal effects will wipe out the NLME (for the geometry of our experiments) for fields below about $0.8 \sim 1 H_{c1}$. However, the estimate of H_{c1} from the weakly 3D argument is [1] $\Phi_0/(2\pi\lambda_0\lambda_{0c})$ (where Φ_0 is the flux quantum, and λ_0 and λ_{0c} are the zero temperature penetration depths for currents flowing in the a-b plane and along the c axis, respectively), which leads to a value of H_{c1} of 20 G or less. This is over an order of magnitude below the experimental value of the field at which first flux penetration occurs which is [3] about 300 Oe. This has been verified by measuring m vs H with H applied in the a-b plane, in two different samples of very high quality YBCO made by different groups, using different crucibles [7]. Below the "field of first flux entry" (FFE), the deviation from linearity, quantified by $(m - m_{\mathrm{Meissner}})/m_{\mathrm{Meissner}}$ in the m vs H data, is less than 0.04%, the resolution of our measurements. In our experiments, the samples used have typical dimensions of 1.5 mm $\times$ 1.5 mm $\times$ 50 μm ($a \times b \times c$). Thus, the deviations from linearity correspond to a change in the effective penetration depth of less than 100 Å, small compared to λ_{ab} of approximately 1400 Å. Above the FFE, there is a clear deviation from pure Meissner-like behavior. This leads us to believe that the screening currents in the sample are Meissner-like below the FFE, with possibly a surface barrier preventing any vortex penetration.

Most of the screening current flows in the a-b plane with components along the nodal directions, with the exception of the return currents that flow near the edges in the c-axis direction. For a-b plane currents, nonlocal effects are much smaller than the NLME at fields of 300 Oe. Currents along the c axis do not contribute much to NLME, as they have no components in the nodal directions. Numerical calculations of the effect that account for return currents in a finite size ellipsoidal sample [8] predict only a small increase in NLME of less than 10% from the case of an infinite slab geometry. Thus, for our experimental geometry, the nonlocal contributions are irrelevant.

The same conclusion can be reached even more starkly by starting from the estimate of the characteristic nonlocal energy, given in LHW as $E_{nl} = \xi_{0c}\Delta_0/\lambda_0$. Quasiparticle effects will be ineffective, due to nonlocality, for quasiparticles within an angle of less than ϕ_{nl} from a node, where ϕ_{nl} is determined from the condition $\Delta(\phi_{nl})/E_{nl} \sim 1$. This yields $\phi_{nl} \sim 0.001$, implying that the NLME requires an applied field $H > H_m$ with $H_m/H_0 \sim 0.001$, where H_0 is [5] the characteristic field scale of the NLME. Since H_0 is about [3,5] 8000 Oe, we find that H_m is about 10 G, in rough agreement with the argument in the previous paragraph.

To summarize, we find it quite plausible that the nonlocal effects indeed render the NLME unobservable at fields below 10 or 20 Oe. Since the experiments are performed at fields over 1 order of magnitude larger, however, with the sample remaining in the Meissner state, it is obvious that the explanation for our negative result must lie elsewhere. In our opinion [3] the presence of at least a few percent component of imaginary s or d_{xy} character in the gap remains the most likely explanation.

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Received 15 December 1998
PACS numbers: 74.25.Nf, 74.20.Fg

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0031-9007/99/83(4)/887(1)$15.00