Harris, Ong, and Yan Reply: In 90 K $YBa_2Cu_3O_7$ (YBCO) we measured a flux-flow Hall resistivity ρ_{xz} (with field $\mathbf{H}\perp\mathbf{c}$) that is negative, in contrast with $\rho_{xy}(\mathbf{H}\parallel\mathbf{c})$ which is positive except within the negative-sign anomaly [1]. If the Hall signal derives *entirely* from vortex motion (as we had assumed), the sign change versus the tilt angle θ seemed incompatible with the scaling model. However, as Geshkenbein and Larkin (GL) [2] point out, a sign change is possible in a two-component model [3] if the Hall conductivity of the vortices σ_{xy}^s and the quasiparticles σ_{xy}^n have opposite signs. GL's scaling relationships provide a semiquantitative way for us to compare data in Ref. [1], and new measurements, with the two-component model, using the conductivity tensor.

We show in Fig. 1(a) the field dependence of $\sigma_{xy}(\theta,H)$ in an untwinned crystal at 84 K for different values of θ. Unlike the nonmonotonic behavior in ρ_{xy} within the negative-anomaly region, σ_{xy} is strictly monotonic in H at all angles. Starting at very large negative values at the threshold for dissipation, σ_{xy} rapidly decreases in magnitude, subsequently becoming positive. In the high-field limit, $\sigma_{xy}(0,H)$ approaches the form $AH\text{-}C/H$. This implies that $\sigma_{xy}^n \sim H$, while $\sigma_{xy}^s \sim -1/H$ at high fields. In Fig. 1(b) we test GL's equation $\sigma_{xy}(\theta,H)=(H_z/\varepsilon_\theta H)\sigma_{xy}^c(\varepsilon_\theta H)$ by rewriting it as $\sigma_{xy}(\theta,H)\sqrt{1+\varepsilon^2\tan^2\theta}=\sigma_{xy}^c(\varepsilon_\theta H)$, where $\varepsilon_\theta=\sqrt{\cos^2\theta+\varepsilon^2\sin^2\theta}$. This equation predicts that curves taken at different θ should collapse onto a universal curve when plotted against H. Figure 1(b), in fact, provides striking confirmation of this scaling behavior, with $\varepsilon=1/7$.

A second test of scaling compares the out-of-plane Hall conductivity σ_{xz} to the in-plane Hall conductivity, via $\sigma_{xz}(\pi/2,H)=\varepsilon\sigma_{xy}^c(\varepsilon H)$. Assuming the validity of this equation, we have converted $\sigma_{xz}(\pi/2,H)$ into $\sigma_{xy}(0,H)$ [solid lines in Fig. 1(c)]. [$\sigma_{xz}(\pi/2,H)$ is derived from $\rho_{xz}(\pi/2,H)$ and $\rho_{xx}(\pi/2,H)$.] For comparison, we also display $\sigma_{xy}(0,H)$ measured *directly* in an untwinned crystal (broken lines). The agreement between the solid and broken lines is rather convincing, considering that there are no free parameters and that $\rho_{xz}(\pi/2,H)$ differs greatly from $\rho_{xy}(0,H)$ in magnitude *and* field dependence.

The analyses here (and to be reported elsewhere [4]) provide strong support for the scaling model. Near T_c, a large (positive) quasiparticle Hall current dominates the *negative* vortex term at high fields, whereas the reverse is true at low fields [see Fig. 1(b)] (the additivity applies to σ_{xy} rather than the Hall angle [5]). This competition provides a rather compelling explanation of the negative-sign anomaly seen in ρ_{xy}. By contrast, when $\mathbf{H}\perp\mathbf{c}$, the vortex contribution to σ_{xz} is 10 times larger than σ_{xz}^n at all fields up to 14 T. Hence, ρ_{xz} is primarily determined by σ_{xz}^s. This scenario also explains the sign change in ρ_{xy} observed [4] in "60 K" YBCO crystals below 40 K. At low temperatures and high fields, σ_{xy} fits well to $-1/H$ (without the AH term). In view of these results, we no longer regard our interlayer-segment model as tenable.

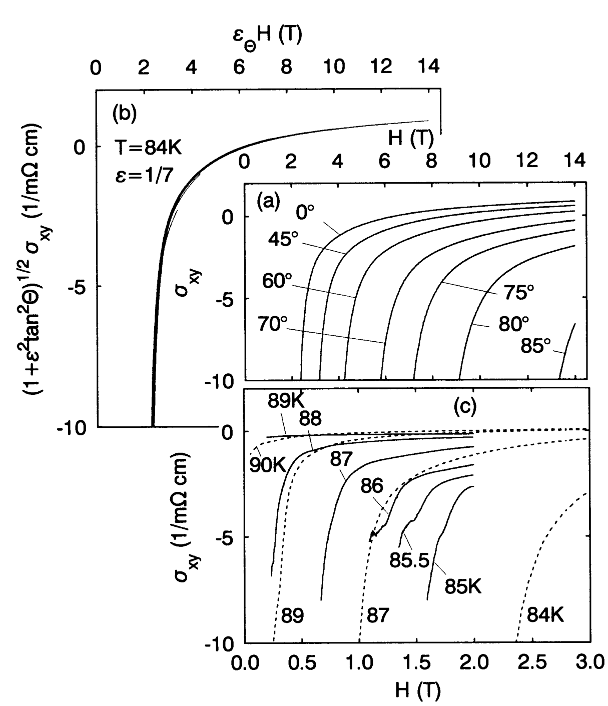

FIG. 1. (a) shows $\sigma_{xy}(\theta,H)$ measured at 84 K in an untwinned crystal of 90 K YBCO (θ is the angle between $\mathbf{H}$ and $\mathbf{c}$). In (b), we test GL's scaling relationship, written as $\sigma_{xy}(\theta,H)\sqrt{1+\varepsilon^2\tan^2\theta}=\sigma_{xy}^c(\varepsilon_\theta H)$, where $\sigma_{xy}^c(H)\equiv\sigma_{xy}(0,H)$ and $\varepsilon_\theta=\sqrt{\cos^2\theta+\varepsilon^2\sin^2\theta}$. All the curves in (a), multiplied by $\varepsilon_\theta/\cos\theta$ with $\varepsilon=1/7$, collapse onto one curve when plotted against H. In (c) we display (as solid lines) $\sigma_{xy}(0,H)$ *calculated* from the out-of-plane Hall conductivity $\sigma_{xz}(\pi/2,H)$ via the scaling relationship $\sigma_{xz}(\pi/2,H)=\varepsilon\sigma_{xy}(0,\varepsilon H)$ with $\varepsilon=1/7$. $\sigma_{xy}(0,H)$ measured directly in an untwinned crystal is shown as broken lines.

J. M. Harris, N. P. Ong, and Y. F. Yan
Department of Physics
Princeton University
Princeton, New Jersey 08544

Received 14 March 1994
PACS numbers: 74.60.Ge, 74.25.Fy, 74.72.Bk

[1] J. M. Harris, N. P. Ong, and Y. F. Yan, Phys. Rev. Lett. **71**, 1455 (1993).
[2] V. B. Geshkenbein and A. I. Larkin, preceding Comment, Phys. Rev. Lett. **73**, 609 (1994).
[3] A. Dorsey, Phys. Rev. B **46**, 8376 (1992); N. B. Kopnin, B. I. Ivlev, and V. A. Kalatsky, J. Low Temp. Phys. **90**, 1 (1993).
[4] J. M. Harris, Y. F. Yan, O. K. C. Tsui, Y. Matsuda, and N. P. Ong (to be published).
[5] M. N. Kunchur *et al.*, Phys. Rev. Lett. **72**, 2259 (1994). Kunchur *et al.* analyze their results assuming additivity in the Hall *angle*.

0031-9007/94/73(4)/610(1)$06.00