Comment on "Hall Effect of Vortices Parallel to CuO_2 Layers and the Origin of the Negative Hall Anomaly in $YBa_2Cu_3O_{7-\delta}$"

In a recent Letter [1] Harris, Ong, and Yan (HOY) reported about the angular dependence of the Hall resistivity in $YBa_2Cu_3O_{7-\delta}$ (YBCO). They have found that, whereas the Hall resistivity ρ_{xy} for $\mathbf{H} \parallel \mathbf{c}$ exhibits a sign change from a positive to a negative value under cooling, ρ_{xz} for $\mathbf{H} \parallel \mathbf{ab}$ does not show this sign change, being negative above and below T_c. Based on these novel findings HOY put forward a very simple and elegant explanation of the origin of the negative Hall anomaly: (1) The "Magnus force" component along the current is opposite in sign for interlayer segments and pancakes, being negative for the former. Near T_c, thermally induced interlayer segments give the main contribution to the Hall effect producing the negative Hall anomaly. (2) Cooling away from T_c as well as twin boundary pinning suppress the transverse fluctuations of the vortex lines, and thereby reduce the population of interlayer segments and lead to an increase of ρ_{xy} in the positive direction. In this Comment we fix the weak points in HOY's arguments and give another explanation of the experiment [1].

Contrary to the main statement of HOY we will show that interlayer segments do not contribute to the Hall effect. The division into pancakes and interlayer segments is valid only for strongly layered superconductors with strong "intrinsic pinning." For this case the force balance equation should be written in the form [2] $\eta \mathbf{v}_\mathbf{L} + \alpha \mathbf{v}_\mathbf{L} \times \mathbf{n} = (\Phi_0/c)\mathbf{j} \times \mathbf{n} + \mathbf{F}_{\text{pin}}$. Without pinning force $\mathbf{F}_{\text{pin}}$ the Hall current is proportional to the constant α which can have different signs for different vortex directions $\mathbf{n}$. Because of intrinsic pinning the interlayer segments are moving in the a-b plane, $\alpha \mathbf{v}_\mathbf{L} \times \mathbf{n}$ is directed along the c axis, and is compensated by $\mathbf{F}_{\text{pin}}$ giving no contribution to the Hall current. In [1] the $\alpha \mathbf{v}_\mathbf{L} \times \mathbf{n}$ term was replaced by the force directed along the current [Eq. (1) of [1]]. Since there is no independent force term directed along the current in force equation [2] such a replacement is possible only in the absence of pinning.

It seems that in [1] intrinsic pinning is weak and a continuous anisotropic theory should be applied. Based on the time-dependent Ginzburg-Landau theory (TDGL) we will argue that even for this case the thermal fluctuations of vortices do not lead to a negative Hall effect. In this theory [3] the Hall conductivity is the sum of a normal and a superconducting part $\sigma_H = \sigma_H^n + \sigma_H^s \sigma_H^s$ is determined only by the imaginary part of the relaxation time γ_2 and has the same sign for any vortex direction. The normal state Hall conductivity is a linear function of $\mathbf{H}$ and can be described by the two parameters σ_{xy}^c and σ_{xz}^{ab} which have different signs in YBCO [1]. It depends not on the vortex direction but on the direction of magnetic field which does not fluctuate at $H \gg H_{c_1}$.

As we will show the angular dependence of the Hall resistivity in [1] is well described by the anisotropic mass model. The results of this model as well as deviations from it can be easily obtained in the scaling approach [4]. In this approach one can show that $\rho_{ik}(H) = \rho_{xy}^c(\tilde{H})\epsilon_{ikl}H_l/\tilde{H}$, where $\tilde{H} = (H_z^2 + H_\perp^2 \varepsilon^2)^{1/2}$ is rescaled field, $\varepsilon = \lambda_{ab}/\lambda_c$ is the anisotropy ratio. This formula is valid in the superconducting state where the normal contribution is already small. Then we have $\rho_{xz}(H) = \varepsilon^{-1}\rho_{xy}^c(\varepsilon H)$. According to this expression the minimum of $\rho_{xz}(H)$ has a larger $(1/\varepsilon)$ value, and is broader and shifted to higher fields (H/ε) than the minimum of ρ_{xy}^c in agreement with [1].

Pinning by point disorder does not change the scaling behavior, it only renormalizes $\rho_{xy}^c(\tilde{H})$. It was argued in [2] that the Hall conductivity does not depend on pinning and the vanishing of the Hall resistivity $\rho_H = \rho\sigma_H\rho$ is due to the rapid drop of ρ because of pinning. This naturally explains why the minimum in ρ_H coincides with the onset of pinning. For $H_z \gg \varepsilon H_\perp$ the scaling law means that ρ_{xy} is determined only by H_z. Deviations from this behavior for $H < H_{\min}$ can be caused by the anisotropy of pinning centers. The cusp in ρ_{xy} for $\mathbf{H}$ near to the $\mathbf{c}$ axis is related to the drop of ρ due to the twin boundary pinning. After rescaling [4] the length scales along the $\mathbf{c}$ axis are increased by $1/\varepsilon$. Thus originally isotropic defects will be elongated along the $\mathbf{c}$ axis in the "isotropic" system. Pinning by these "elongated" defects will also be anisotropic, being weaker when $\mathbf{H}$ turns towards the a-b plane, which can explain the slight deepening of the minimum in ρ_{xy} with increasing $H_\perp$ in [1].

Thus the experimental data [1] are in good agreement with the anisotropic scaling of superconducting properties. This scaling follows directly from the anisotropic TDGL theory. In this phenomenological theory the Hall conductivity is described by three independent parameters σ_{xy}^n, σ_{xz}^n, and γ_2, which should be calculated from microscopic theory. In a simple Fermi liquid theory all these quantities have the same sign and the sign change of the Hall resistivity in high T_c superconductors and some conventional superconductors remains a great puzzle for such a theory. Within a resonating valence bond theory the results of [1] can indicate that σ_{xy}^n is dominated by holons, whereas the superconducting properties (γ_2) is dominated by spinons.

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