Comment on "3D X-Y Scaling of the Specific Heat of $YBa_2Cu_3O_{7-\delta}$ Single Crystals"

In a recent Letter [1], it was suggested that the scaling characteristic of only the three-dimensional (3D) *XY* model was valid for specific heat measurements in applied magnetic fields H in high temperature superconductors (HTSC's). This is in contrast to magnetization and resistivity measurements where the scaling characteristic of lowest Landau level (LLL) theory as well as 3D *XY* scaling has been used with success. This is also in contrast to recent works on $LuBa_2Cu_3O_{7-\delta}$ (LBCO) [2] and $(Bi,Pb)_2Sr_2Ca_2Cu_3O_x$ [3], where it was demonstrated that finite-field specific heat data could be scaled using LLL theory. The authors of Ref. [1] tried to discredit the work on LBCO [2] by stating that the inclusion of the term bt in the mean-field specific heat $C_{\mathrm{MF}} = \gamma T(1 + bt)$ was unjustified. While this term is indeed often neglected because it is small, it is nonetheless a valid term included in standard textbooks [4]. Those authors [5] have also criticized the LLL scaling on LBCO because γ was adjusted for each data set. This was done to correct for experimental drift which is reflected in Fig. 1 of Ref. [2]. When one redoes this scaling holding γ constant and takes into account the error bars, the results are still consistent with LLL scaling. Thus, the reasons given [1,5] to reject LLL scaling appear to be invalid.

To demonstrate this point, we have applied 3D LLL scaling to the specific heat data on a $YBa_2Cu_3O_{7-\delta}$ (YBCO) sample [6]. The scaling form [7] is $[C(H,T) - C_b(T)]/C_{\mathrm{MF}}(T) = g(x)$ where $C_b(T)$ is the background contribution, and $x = [T - T_c(H)]/[k_B H T^2/4C_{\mathrm{MF}}(T) \times \phi \xi_c \sqrt{T_c}\,]^{2/3}$. Our results are shown in Fig. 1. $C_b(T)$, $C_{\mathrm{MF}}(T)$, and $T_c(H)$ were determined in the same way as in Ref. [2], omitting a window around $T_c = 90.8$ K of width ± 2 K. The symbols in x have the same meaning as in that reference. Because the raw data collapse far below T_c, we did not have to adjust γ for each value of H. One can see the data scales quite well. The 7 T data set does not scale as well above the peak, but this can be attributed to experimental drift (see Ref. [6]). In contrast to 3D *XY* scaled data, there is a theoretical curve to which one can compare the LLL scaled data. In the figure, we have plotted the theoretical curve [7] (with $\xi_c = 1$ Å) that one would expect for 3D system in the presence of a magnetic field. The good agreement between the theoretical curve and the scaled data demonstrates the validity of LLL scaling.

We note that many of the results found in Ref. [2] regarding the 2D-3D nature of these materials were also found for the data of Ref. [6]. For example, 2D LLL scaling was found to work better than 3D LLL scaling for the data away from the peaks but not as well at the peak. Furthermore, LLL scaling started to break down for fields less than 1 T. We were unable to scale the data of Ref. [1] with LLL theory. We believe that this is due to a smaller correlation length in that sample.

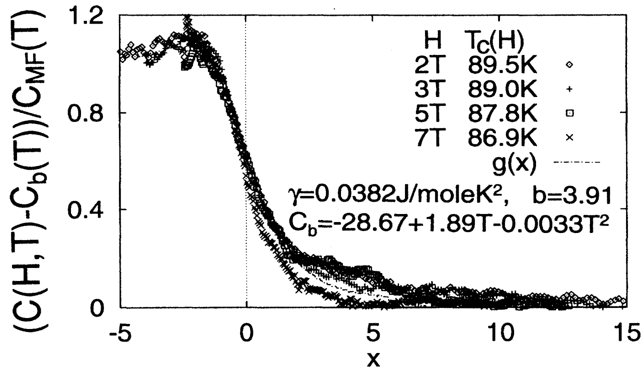

FIG. 1. The data of Ref. [6] scaled with LLL theory.

Determining $T_c(H)$ by inflection point, we find $dT_c/dH \simeq -0.24$ K/T for that sample and $dT_c/dH \simeq -0.48$ K/T for the samples of Refs. [2,6]. The factor of 2 difference implies [4] that the correlation length of the sample of Ref. [1] is $\frac{2}{3}$ the size of that in the other samples. This analysis is consistent with Ref. [3] where LLL scaling was used successfully and $dT_c/dH \simeq -0.5$ K/T.

In conclusion, we have shown that LLL scaling does describe specific heat data in LBCO and YBCO samples. This suggests that there is significant overlap of the regimes where 3D *XY* scaling and LLL scaling are valid, contrary to what is suggested in Fig. 1 of Ref. [1]. Since data taken on the same materials [1,6] yield conflicting results, it is clear that more work needs to be done on these materials as well as other HTSC's.

We wish to acknowledge Z. Tešanović and A. Dorsey for useful conversations. We also thank S. Inderhees *et al.* and N. Overend *et al.* for providing their data. This work was supported by a National Research Council RA.

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Received 19 September 1994
PACS numbers: 74.25.Bt, 64.60.Fr, 74.20.De

[1] N. Overend *et al.*, Phys. Rev. Lett. **72**, 3238 (1994).
[2] B. Zhou *et al.*, Phys. Rev. B **47**, 11 631 (1993).
[3] N. Kobayashi *et al.*, Physica (Amsterdam) **219C**, 265 (1994).
[4] M. Tinkham, *Introduction to Superconductivity* (Krieger, Malabar, 1980); A. Abrikosov *et al.*, *Methods of Quantum Field Theory in Statistic Physics* (Dover, New York, 1975).
[5] N. Overend *et al.*, Physica (Amsterdam) **235–240C**, 1769 (1994).
[6] S. E. Inderhees *et al.*, Phys. Rev. Lett. **66**, 232 (1991).
[7] D. J. Thouless, Phys. Rev. Lett. **34**, 946 (1975).