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June 1991

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N.E. Phillips, R.A. Fisher, D.A. Wright, A. Amato and R. Caspary

Materials and Chemical Sciences Division, Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

H.B. Radousky

Lawrence Livermore National Laboratory
Livermore, California 94550

J.L. Peng, L. Zhang and R.N. Shelton

Department of Physics
UC-Davis, Davis, CA 95616

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N.E. PHILLIPS, R.A. FISHER, D.A. WRIGHT, A. AMATO°, R. CASPARY+, H.B. RADOUSKY[1], J.L. PENG[2*], L. ZHANG[2] and R.N. SHELTON[2]

Materials Sciences Division, LBL, Berkeley, CA 94720 USA; [1]LLNL, Livermore, CA 94550 USA; [2]Department of Physics, UC-Davis, Davis, CA 95616 USA

Specific2-heat measurements on $(Y_{1-x}Pr_x)Ba_2Cu_3O_7$, x=0, 0.1, 0.2, 0.3, 0.6, 0.8 and 1; $0.3 \leq T \leq 100K$; and in magnetic fields to 7T are reported. The combination of low-temperature and in-field data allows the separation of hyperfine and magnetic ordering contributions from the low-temperature linear term, γT.

$(Y_{1-x}Pr_x)Ba_2Cu_3O_7$ has the orthorhombic structure, but is superconducting only for $x<0.55$. The first measurements of the specific heat (C) were analyzed to have large values of the coefficient (γ) of the "linear" term γT, and were interpreted as showing "heavy-fermion-like" behavior[1]. Subsequent extensions of the measurements of C to lower temperatures[2,3] and in magnetic fields[2] (H) has shown that magnetic ordering of the Pr ions contributed to C in the T-interval in which γ was determined. Consequently, the values of γ that appear relevant to the conduction electron system are lower, although still large[2,3]. The measurements[2] were also analyzed to give values of the effective hyperfine field (H_h) at the Pr nuclei.

Magnetic ordering and electronic contributions to C (x=0.1 and 0.3), obtained by subtracting the hyperfine contribution and (for the "background") the total C for x=0, are displayed in Fig.1. The horizontal lines are the values of γ(7T) determined from a least-squares fit of C to $C=D_{-2}T^{-2}+\gamma T+B_3T^3$ below 1K. [For $x<0.55$ γ (7T)~γ(0)]. The large values of γ and the presence of a cut-off T at ~50K adds to the appearance of heavy-fermion-like behavior. [The small feature near 40K (x=0.3) may be associated with the transition to the superconducting state.] Entropies associated with the magnetic ordering anomalies are (1/2)Rln2 per mole Pr for x=0.1, 0.2 and 0.3 (H=7T) and x=0.3 (H=0).

Present addresses: °ETH, Zurich, Switzerland; +Technische Hochschule Darmstatdt; Darmstatdt, FRG; *Department of Physics, University of Maryland, College Park, MD 20742 USA.

Figure 2 is a plot showing the anomaly in C/T for H=0 near T_c=86K (x=0.1) which is very much attenuated compared with those observed for x=0. In 7T the anomaly is completely suppressed. The decrease in $\Delta C(T_c)/T_c$ could indicate a decrease in the density of electronic states due to a hybridization of the Pr ions with the CuO_2 planes. No anomaly at T_c was observed for x=0.2.

The specific heat in the insulating region (x>0.55) is shown in Fig. 3. For x=1 there is a broad anomaly in C which is centered at ~17K. At x=0.8 and 0.6 there is a progressive shifting and broadening of the anomaly to ~10K and ~5K, respectively. A 7T magnetic field produces a slight attenuation of the anomalies accompanied by a small shift to lower temperatures relative to H=0. [The present results for C (x>0.55) are similar to those reported previously for H=0[1,3].] At low temperatures, T<2K, C for each of the three samples can be fitted to $C=D_{-2}(H)T^{-2}+\gamma(H)T+A_3(H)T^3$, as illustrated for x=1 in the insert to Fig. 3. The term in T^3 indicates three-dimensional antiferromagnetic spin waves while the T^{-2} term is a result of interaction of the Pr nuclei with H. The presence of a γT term is surprising since for x>0.55 the $(Y_{1-x}Pr_x)Ba_2Cu_3O_7$ 2system is insulating. It might arise because of the Pr hybridization with the CuO_2 planes. Both $\gamma(H)$ and $A_3(H)$ are plotted vs. H in Fig. 4. In contrast to the superconducting region of the phase diagram, γ is strongly suppressed as H increases.

Figure 5 is a plot of $\gamma(0)$ and $H_h(H)$ vs. x for a mole of Pr. There is a linear decrease of $\gamma(0)$ with x, with no discontinuity at the boundary between the superconducting and insulating regions, in contrast to other reported values[3]. $H_h(7T)=100\pm5T$ and is independent of x. For H<7T there is a non-linear enhancement of $H_h(H)$ as x increases.

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3. S. Ghamaty et al., Phys. Rev. B43, 5430 (1991).

FIGURE CAPTIONS:

Fig. 1. Magnetic ordering components of C.

Fig. 2. $\Delta C(T_c)/T_c$ for $x=0.1$.

Fig. 3. Antiferromagnetic ordering for $x>0.55$.

Fig. 4. Variation of γ and A_3 with H.

Fig. 5. Variation of $\gamma(0)$ and $H_h(H)$ with x.

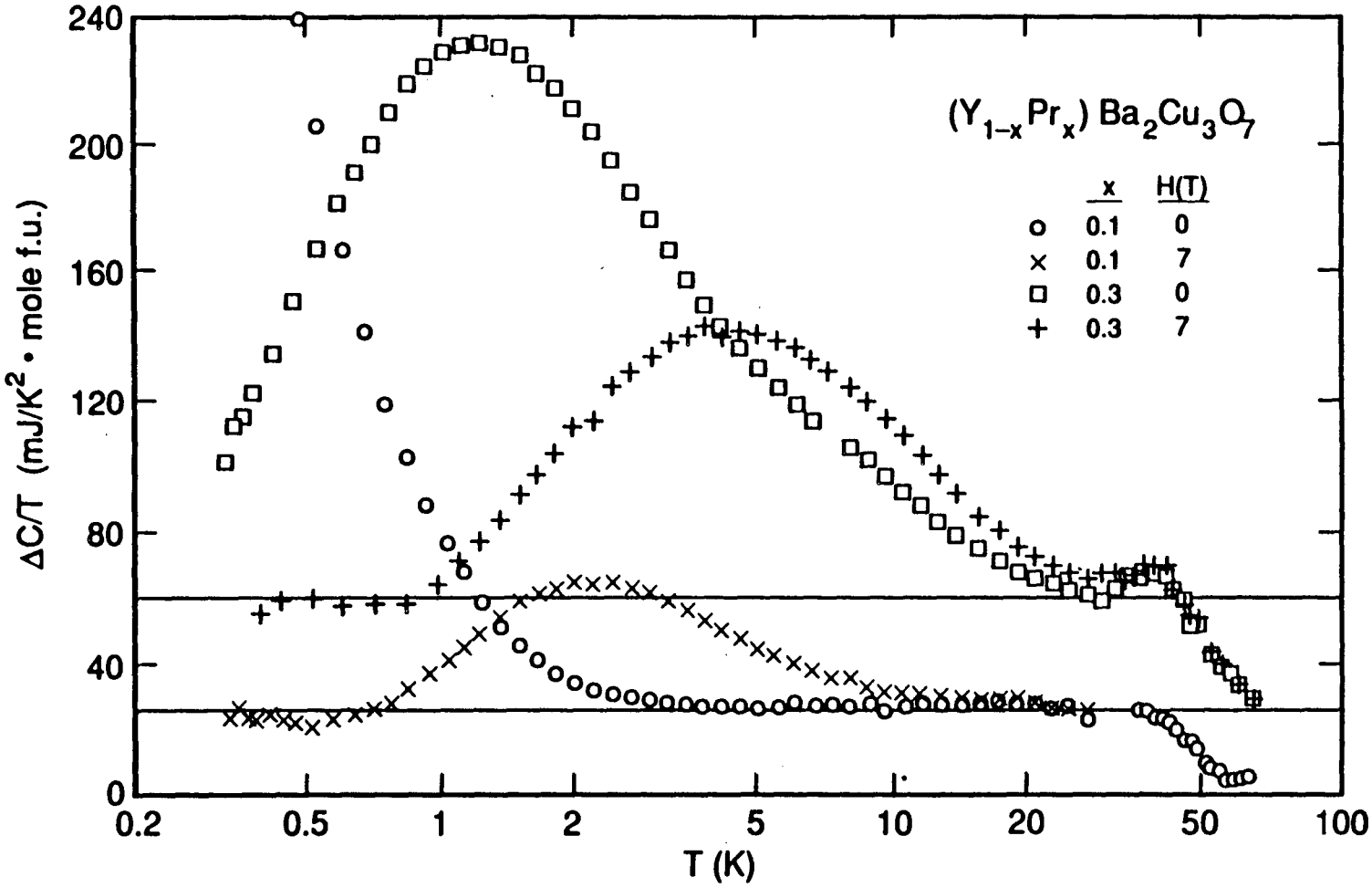

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FIGURE 1

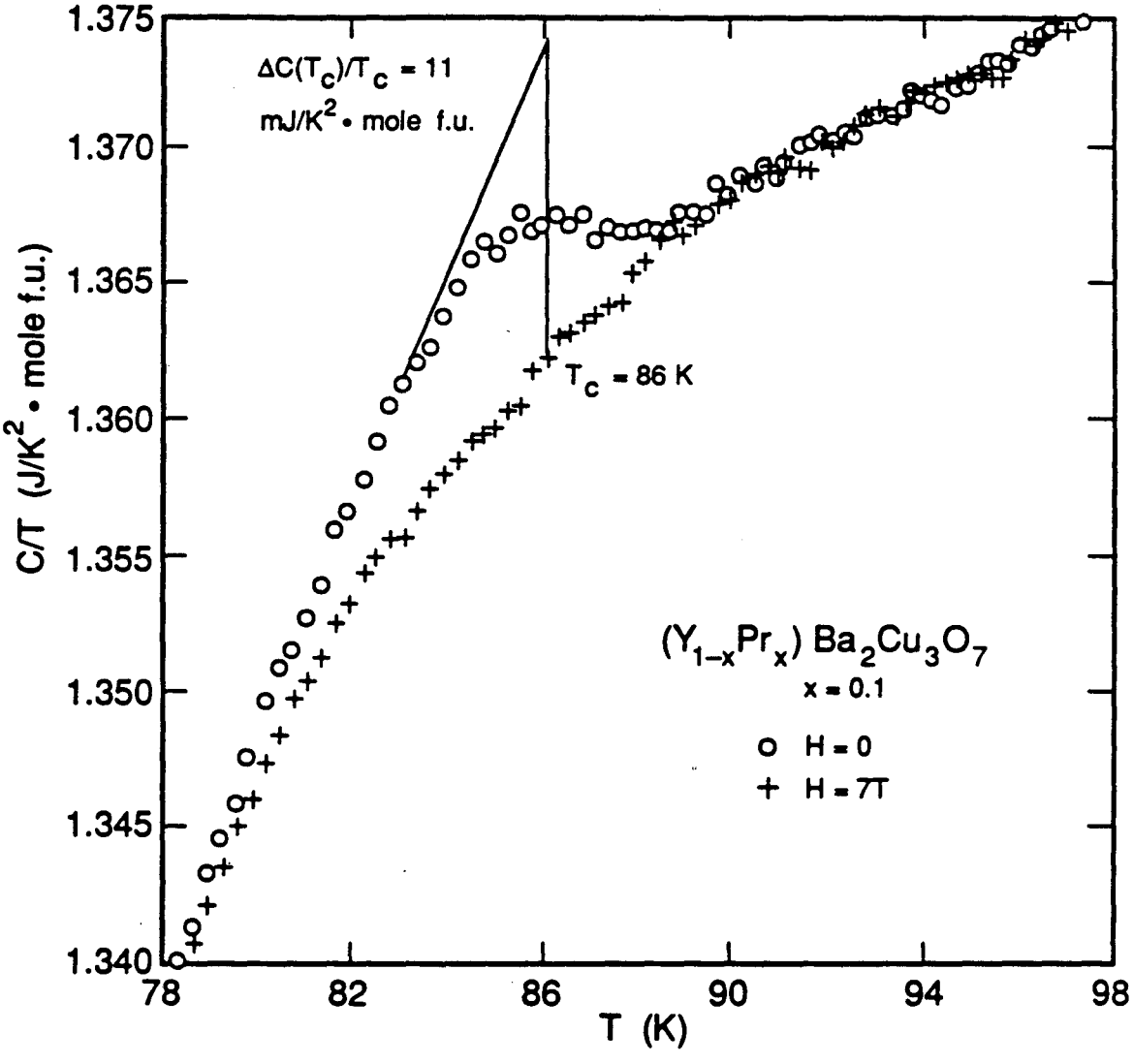

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FIGURE 2

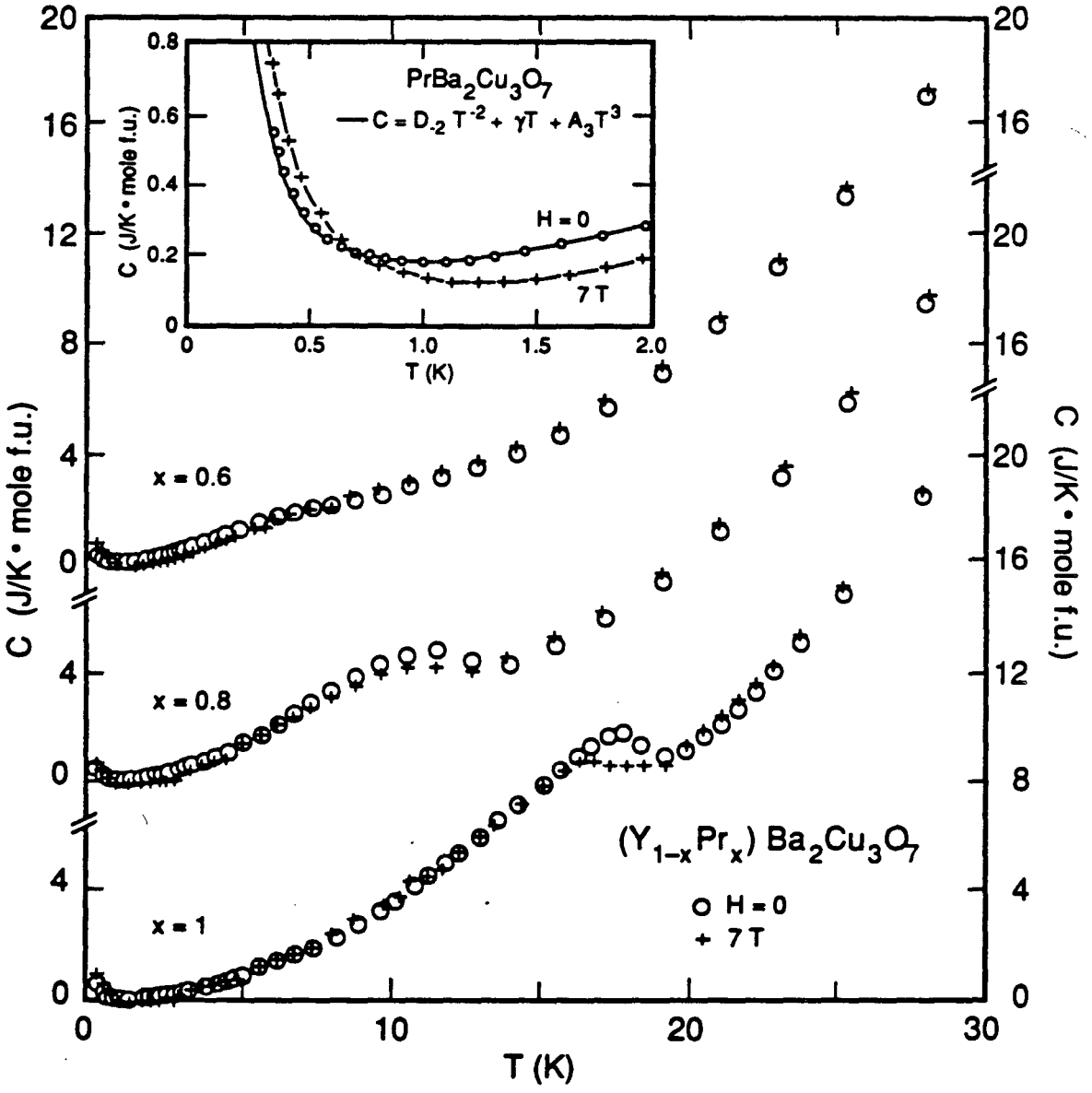

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FIGURE 3

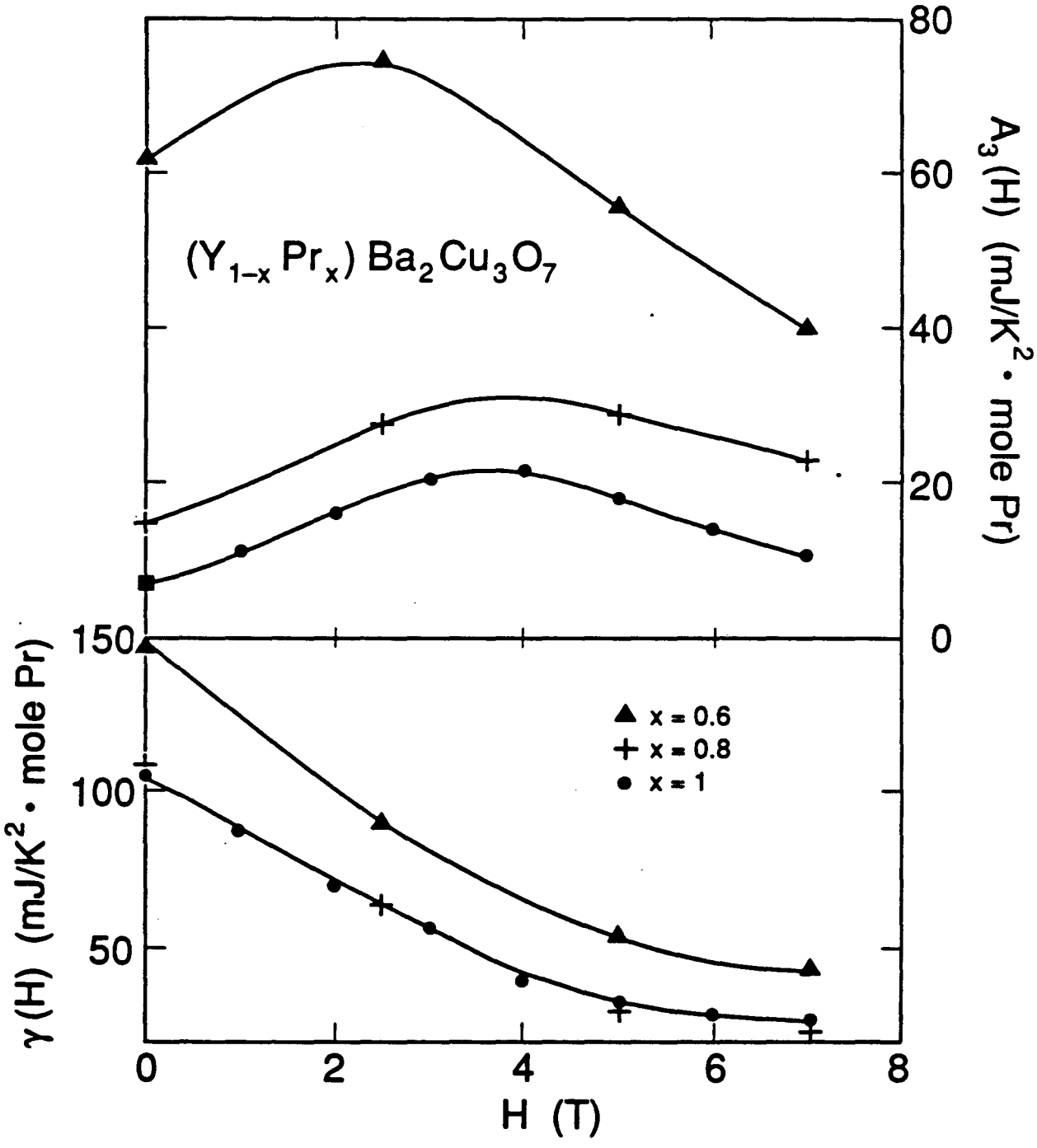

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FIGURE 4

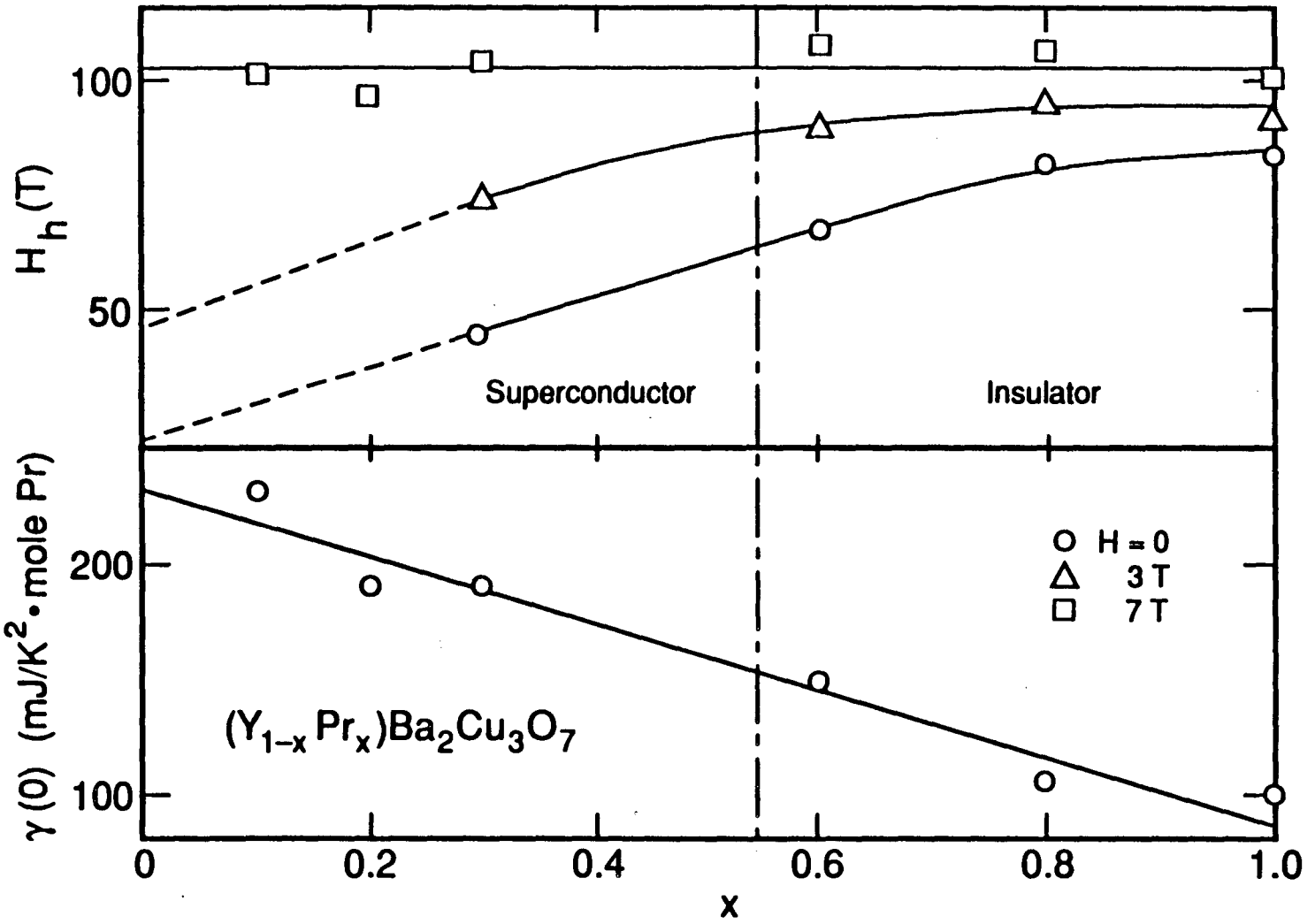

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FIGURE 5

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