Title
Field-induced transitions in Y2Cu2O5

Journal
Physical Review B, 38(10)

ISSN
2469-9950

Authors
Cheong, S-W
Thompson, JD
Fisk, Z
et al.

Publication Date
1988-10-01

DOI
10.1103/physrevb.38.7013

Field-induced transitions in $Y_2Cu_2O_5$

S-W. Cheong, J. D. Thompson, Z. Fisk, K. A. Kubat-Martin, and E. Garcia
Los Alamos National Laboratory, Los Alamos, New Mexico 87545
(Received 8 July 1988)

Magnetic susceptibility and isothermal magnetization measurements on single crystals of $Y_2Cu_2O_5$ show evidence for two field-induced phase transitions that develop out of an antiferromagnetic ground state.

The antiferromagnetic insulator La_2CuO_4 has received considerable attention since the discovery[1] that doping this material with a divalent atom such as Sr or Ba results in superconductivity near 40 K. Because of the possible connection between superconductivity in the doped material and magnetic order in the host, the nature of magnetic correlations in La_2CuO_4 has been studied in some detail.[2–11] Initial neutron scattering experiments[2–4] on sintered powder samples of La_2CuO_4 showed that antiferromagnetic order at $T_N \sim 250$ K (the precise value of T_N depending on oxygen stoichiometry) resulted from antiferromagnetic coupling of the Cu $3d^9$ spins in the orthorhombic CuO_2 basal plane. However, magnetic susceptibility measurements for $T \gtrsim T_N$ indicated a positive paramagnetic Curie temperature θ, suggesting the presence of ferromagnetic interactions. More recent magnetic-susceptibility and magnetoresistance measurements[8–10] on single crystals of La_2CuO_4 revealed a metamagnetic transition at $T \leq T_N$ for fields applied perpendicular to the CuO_2 basal plane. The origin of this field-induced transition has been demonstrated[11] by neutron scattering to arise from canting of the Cu spins out of the basal plane, a condition produced by the rotationally distorted octahedral coordination of oxygen atoms around the Cu.

Given the interest in La_2CuO_4, it is worthwhile to study other examples of Cu-O systems that might show similar magnetic behavior. $Y_2Cu_2O_5$, a common second phase found when producing the 90-K superconductor $YBa_2Cu_3O_7$, is a potential candidate for undergoing a field-induced transition. The magnetic properties of powder samples of this compound have been measured by Troc, Bukowski, Horyn, and Klamut[12] who found antiferromagnetic order at $T_N = 13$ K but also a positive $\theta = 38.5$ K. Further, oxygen coordination about Cu forms an irregular hexahedron. To investigate the possibility of a field-induced transition we have determined the anisotropic susceptibility and isothermal magnetization of single crystals of $Y_2Cu_2O_5$.

Small parallelopiped crystals were prepared as a by-product of flux-grown $YBa_2Cu_3O_x$ crystals. Single-crystal x-ray diffraction showed an orthorhombic crystal structure (space group $Pna2_1$) with lattice parameters $a = 10.782(2)$ Å, $b = 3.4870(7)$ Å, and $c = 12.446(1)$ Å, results similar to those reported[13] for $Ho_2Cu_2O_5$ in which there are two inequivalent Cu sites per cell. Susceptibility/magnetization were performed with a quantum design superconducting-quantum-interference-device-based (SQUID-based) system.

Figure 1 shows the magnetic susceptibility χ of $Y_2Cu_2O_5$ measured in a 0.5-T field applied parallel ($\chi_\parallel$) and perpendicular ($\chi_\perp$) to the orthorhombic b axis. Clear

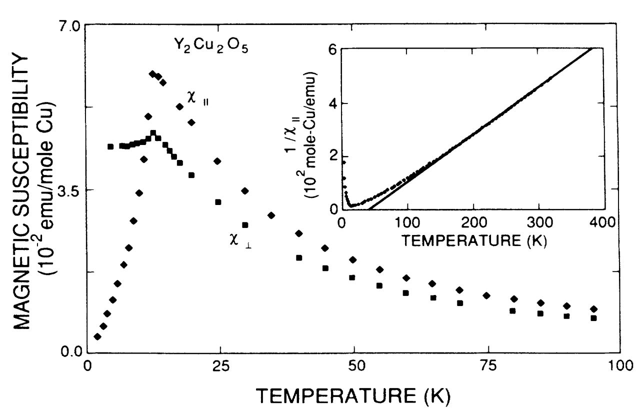

FIG. 1. Magnetic susceptibility of $Y_2Cu_2O_5$ measured in a 0.5-T field applied parallel ($\chi_\parallel$) and perpendicular ($\chi_\perp$) to the orthorhombic b axis. The inset shows $1/\chi_\parallel$ vs temperature from which we obtain an effective moment of $2.16\mu_B$ per Cu and a paramagnetic Curie temperature of 37 K.

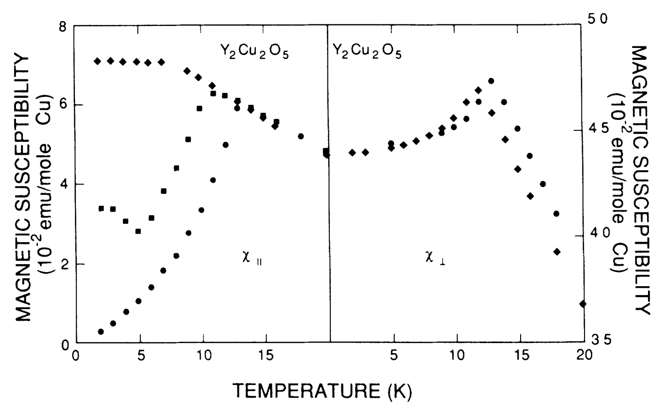

FIG. 2. Magnetic susceptibility of $Y_2Cu_2O_5$ in the vicinity of its Néel temperature. Left panel is for the field parallel to the b axis and the right panel for the field perpendicular to the b axis. Symbols correspond to different fields: 0.5 T (circles), 3 T (squares), 5 T (diamonds).

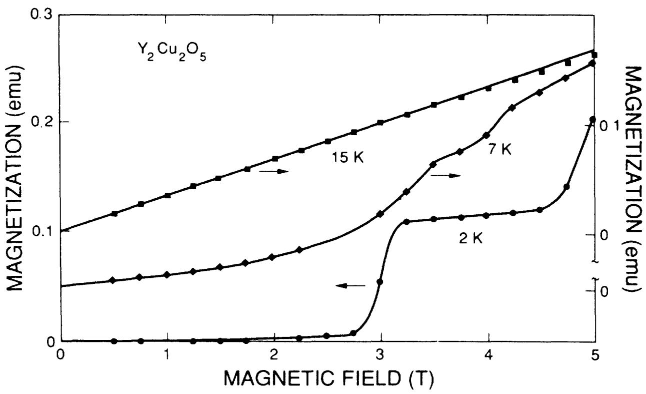

FIG. 3. Isothermal magnetization vs field for fields parallel to the b axis. Note the appearance of two field-induced transitions for $T < T_N$ and the shift in origin for $T = 7$ and 15-K data.

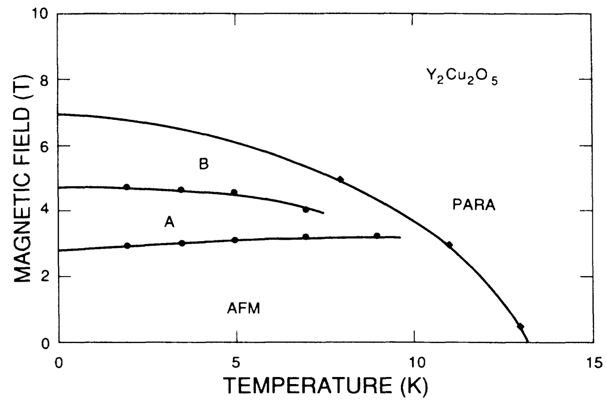

FIG. 4. Field-temperature phase diagram for $Y_2Cu_3O_5$. The boundary separating the paramagnetic phase from other phases was determined from the maximum in χ. Boundaries defining phases A and B were obtained from the field at which dM/dH is a maximum (Fig. 3). AFM represents antiferromagnetic.

evidence for antiferromagnetic order is observed at $T_N \simeq 13$ K. For $150 \leq T \leq 350$ K, plots of $1/\chi_{\parallel}$ and $1/\chi_{\perp}$ versus temperature give θ's of 37 and 38 K, respectively, and effective moments of $2.16\mu_B$ and $1.98\mu_B$ per Cu, respectively. A polycrystalline average of these single-crystal results are in reasonably good agreement with those reported by Troc *et al.*[12] The temperature dependence of $\chi_{\parallel}$ and $\chi_{\perp}$ below T_N is qualitatively that predicted by mean-field theory which would suggest that the direction of the sublattice magnetization is parallel to the b axis. However, Fig. 2 shows that the temperature dependence of $\chi_{\parallel}$ is a strong function of the field in which the measurements are made. For a field of 5 T, $\chi_{\parallel}$ no longer looks mean-field-like. At the same time, $\chi_{\perp}(T)$ is virtually unchanged in a 5 T field, except for a modest depression of T_N.

Representative isothermal magnetization curves, with the field parallel to the b axis, are given in Fig. 3. For $T > T_N$, M vs H is linear and extrapolates through the origin. However, for $T < T_N$, there is clear evidence for two field-induced transitions. At 2 K, a sharp increase in the magnetic moment by $\sim 0.3\mu_B$ per Cu appears at a field of 3 T, followed by another incomplete transition near 5 T. Little, if any, hysteresis was found in either transition. With increasing temperature these phase transitions become less well defined. If the critical field for the transition is defined by the field at which the slope dM/dH is a maximum, we arrive at the field-temperature phase diagram shown in Fig. 4. Given the uncertainty in determining the critical field as $T \to T_N$, the precise H-T dependence of boundaries defining phases A and B should be considered with caution.

From the susceptibility/magnetization data alone, it is not possible to determine unambiguously the nature of phases A and B in Fig. 4. Because $Y_2Cu_2O_5$ is an insulator, superexchange through the oxygen is probably important. Clearly, phase A is weakly ferromagnetic. Because of the anisotropy in χ and irregular hexahedral coordination of oxygen, it is possible that weak ferromagnetism is produced by single-ion anisotropy or possibly antisymmetric spin coupling. However, an analysis using the theory of Dzyaloshinsky[14] and Moriya[15] is complicated by the complex crystal structure of $Y_2Cu_2O_5$. A mean-field analysis of phase B, assuming it to be a spin-flopped state, gives order-of-magnitude agreement with our observations; although, this is by no means definitive. Certainly, additional magnetization measurements to fields greater than 5 T and neutron scattering experiments would be helpful in understanding the field-induced transitions in $Y_2Cu_2O_5$.

The work at Los Alamos was performed under the auspices of the U.S. Department of Energy.

[1]J. G. Bednorz and K. A. Müller, Z. Phys. B **64**, 189 (1986); S. Uchida, H. Tagaki, K. Kitazawa, and S. Tanaka, Jpn. J. Appl. Phys. Lett. **26**, L1 (1987).

[2]D. Vaknin, S. K. Sinha, D. E. Moncton, D. C. Johnston, J. Newsam, C. R. Safinya, and H. E. King, Jr., Phys. Rev. Lett. **58**, 2802 (1987).

[3]K. Yamada, E. Kudo, Y. Endoh, Y. Hidaka, M. Suzuki, and T. Murakami, Solid State Commun. (to be published).

[4]S. Mitsuda, G. Shirane, S. K. Sinha, D. C. Johnston, M. S. Alvarez, D. Vaknin, and D. E. Moncton, Phys. Rev. B **36**, 822 (1987).

[5]G. Shirane, Y. Endoh, R. J. Birgeneau, M. A. Kastner, Y. Hidaka, M. Oda, M. Suzuki, and T. Murakami, Phys. Rev. Lett. **59**, 1613 (1987).

[6]K. B. Lyons, P. A. Fleury, J. P. Remeika, A. S. Cooper, and T. J. Negran, Phys. Rev. B **37**, 2353 (1988).

[7]R. T. Collins, Z. Schlesinger, M. W. Shafer, and T. R. McGuire, Phys. Rev. B **37**, 5817 (1988).

[8]S-W. Cheong, Z. Fisk, J. O. Willis, S. E. Brown, J. D. Thompson, J. P. Remeika, A. S. Cooper, R. M. Aikin, D. Schiferl, and G. Gruner, Solid State Commun. **65**, 111 (1988); S-W. Cheong, J. D. Thompson, Z. Fisk, and G. Gruner, *ibid.* **66**, 1019 (1988).

[9]K. Fukuda, S. Shamoto, M. Sato, and K. Oka, Solid State

Commun. **65**, 1323 (1988).

[10]T. Thio, T. R. Thurston, N. W. Preyer, P. J. Picone, M. A. Kastner, H. P. Jensen, D. R. Gabbe, C. Y. Chen, R. J. Birgeneau, and A. Aharony, Phys. Rev. B **38**, 905 (1988).

[11]M. A. Kastner, R. J. Birgeneau, T. R. Thurston, P. J. Picone, H. P. Jenssen, D. R. Gabbe, M. Sato, K. Fukuda, S. Shamoto, Y. Endoh, K. Yamada, and G. Shirane (unpublished).

[12]R. Troc, Z. Bukowski, R. Horyn, and J. Klamut, Phys. Lett. A **125**, 222 (1987).

[13]H.-R. Freund and Hk. Muller-Buschbaum, Z. Naturforsch. **32B**, 609 (1972).

[14]I. Dzyaloshinsky, J. Phys. Chem. Solids **4**, 241 (1958).

[15]T. Moriya, Phys. Rev. **120**, 91 (1960).