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THERMODYNAMIC CRITICAL FIELD OF $Y_1Ba_2Cu_3O_7$

D. K. Finnemore, M. M. Fang, J. R. Clem, R. W. McCallum, J. E. Ostenson, Li Ji, and P. Klavins

Ames Laboratory and Department of Physics
Iowa State University, Ames, Iowa 50011
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ABSTRACT

The thermodynamic critical field curve has been measured for $Y_1Ba_2Cu_3O_7$ close to the superconducting transition temperature in order to determine the magnitude of the specific heat jump at the transition. The slope of the critical field curve is found to be 165 Oe/K, which corresponds to a specific heat jump of 680 mJ/moleCuK. If the BCS theory applies, this would also imply a density of electronic states of 3.39 states per electron volt-unit cell and the Sommerfeld term, γ=5.3 mJ/moleCuK^2.

INTRODUCTION

Magnetization curves for a superconductor can give important information about the electronic properties of the material.[1] If the magnetization curves are reversible, the free energy difference between the superconducting and normal state is given by the area under the magnetization (M) vs magnetic field (H) curve,

$$\frac{H_c^2}{8\pi} = G_n - G_s = \int_0^{H_{c2}} MdH$$

and the thermodynamic critical field, H_c, is given by $H_c^2/8\pi = G_n - G_s$. The slope of the critical field is then related to the jump in specific heat by the thermodynamic relation,

$$\Delta C = \frac{T_c}{4\pi} \left(\frac{dH_c}{dT}\right)^2 .$$

The goal of this work is to directly measure the thermodynamic critical field close to the transition temperature, T_c, and to derive various electronic properties from it.

For the case of the $(La_{1.85}Sr_{0.15})CuO_2$ superconductor the magnetization was found to be reversible over a wide temperature range.[1] For the $Y_1Ba_2Cu_3O_7$ samples reported here, however, there is only a small window in temperature close to the transition temperature, T_c, of about

4K width where the magnetization curves are reversible but this is quite adequate to determine the slope $(dH_c/dT)_{T=T_c}$. At 86K the uncertainty in the area of the magnetization curve becomes greater than 3% of the area due to hysteresis. In this work, a study of the magnetization curves is presented and the data are analyzed for the jump in specific heat at T_c. Direct measurement of ΔC is difficult because the phonon contribution is so large.

EXPERIMENTAL

Samples were prepared in the form of a sintered pellet by procedures similar to those outlined by other workers.[2-6] Proper amounts of Y_2O_3, $BaCO_3$ and CuO were ground in a mortar and pestle, put in a Pt lined aluminum boat and heated in air for 16 hr at 900°C. This powder was then ground again and fired again in flowing O_2 for 16 hr at 950°C. Different samples of this powder were then pressed into pellets and fired in flowing O_2 at temperatures ranging from 950°C to 1020°C for 16 hr. The furnace was turned off in steps with one hour holds at 100°C intervals, with stops at 900, 800, 700, 600, and 500°C and then furnace cooled to 200°C, a process which took about 6 hours. Several different reaction temperatures were used to determine where the sample began to decompose and deteriorate.

Magnetization measurements were made in a commercial apparatus in which the sample is slowly pulled through a gradiometer connected to a superconducting quantum interference device (SQUID).

RESULTS AND DISCUSSION

Electrical resistivity for these samples are typical to those reported by other groups.[2-6] Between room temperature and T_c, the curve is rather linear and drops from 1200 μΩcm at 300K to 700 μΩcm at 95K for

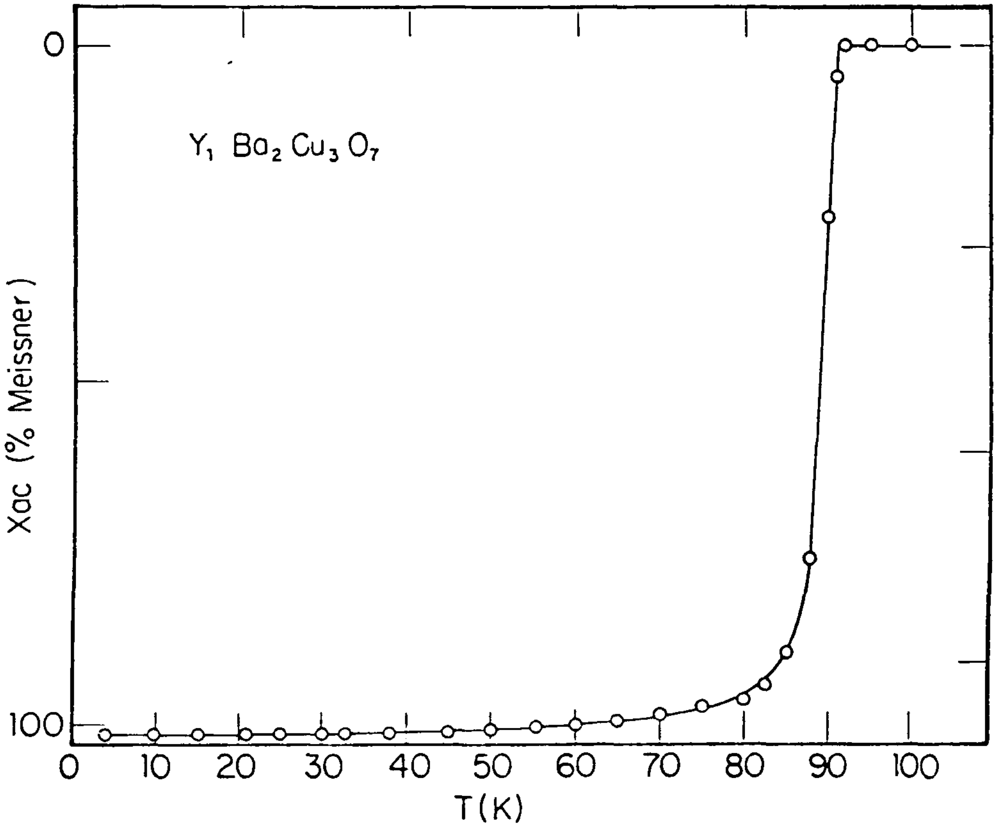

Fig. 1. The ac susceptibility of $Y_1Ba_2Cu_3O_7$ taken at 100 Hz and 1 Oe measuring field.

a typical sample. The temperature interval for the resistive drop at T_c between 90% and 10% of R(95K) was 1.2K. The ac susceptibility at 100 Hz and 1.0 Oe measuring field is shown in Fig. 1. There is a sharp drop at T_c indicating a good quality sample.

Magnetization curves in the normal state shown by the solid line of Fig. 2 are linear in field and give a magnetization of 0.046 emu/cm^3 at 1 Tesla. The curves measured at 95 and 100K are identical to an accuracy of 1%. In the superconducting state, the magnetization rises sharply at the full flux exclusion slope at low temperature. Very close to T_c, the superconducting penetration depth is large so the flux expulsion is not complete.[1]

The magnetization curve for 88K is shown by the solid curve of Fig. 3. The area under the magnetization curve for the magnetic field increasing is the same as that for the magnetic field decreasing to an accuracy of 2%, which is about the accuracy of the magnetization measurements. Using these areas in conjunction with Eq. 1, the critical field is found to be the values shown in Fig. 4. The data give a T_c of 91K, which is the temperature at which the electrical resistivity has dropped below the normal state resistance at 95K by a factor of more than 10,000.

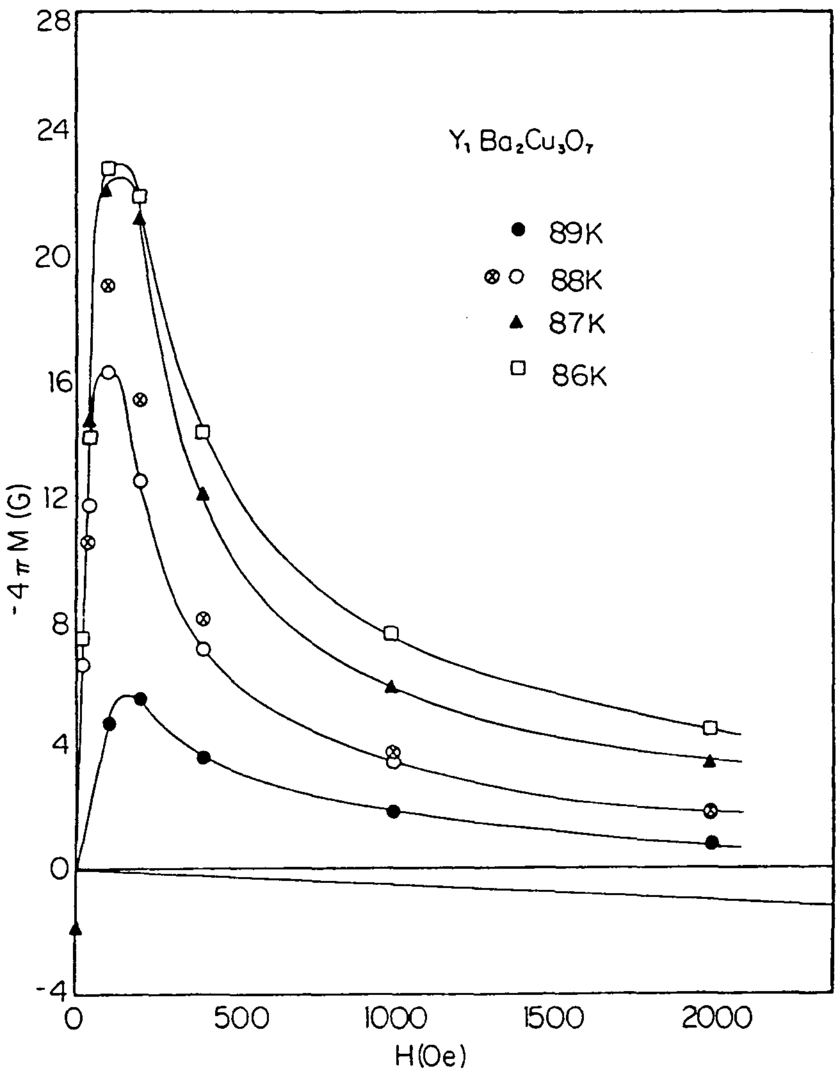

Fig. 2. Low field magnetization data.

The slope dH_c/dT is found to 165 Oe/K, a value rather close to elemental superconductors such as Sn and Pb. Inserting this value into Eq. 2 gives a jump in specific heat at T_c of 19.7 mJ/cm^{3}K or 689 mJ/moleCuK. These values depend only on reversibility of the M vs H curves and the applicability of thermodynamics. There is considerable variation in dH_c/dT for samples with different heat treatment procedures and values range between 102 Oe/K for a sample heat treated at 1020°C and 165 Oe/K for one heat treated 950°C. The higher heat treatment temperatures give much better critical currents, but they have considerable second phase and are not indicative of bulk 123 phase. The sample heat treated at 950°C is indicative of the most pure bulk 123 phase.

An important feature of superconductivity is that there is a great deal of similarity in the critical field curves and there is a law of corresponding states for various materials. A wide variety of elements and compounds show a critical field slope of approximately 170 Oe/K. These measurements show that $Y_1Ba_2Cu_3O_2$ fits well into this pattern. If one assumes that BCS describes the free energy of this material, the density of states can be calculated from the relation:

$$\gamma = 0.0558\ (dH_c/dT)^2$$

and a value of 0.152 mJ/cm^{3}K^2 or 5.3 mJ/moleCuK^2. Using $N(0)=3\ /2\pi^2k^2\gamma$, the density of state is found to be 3.4 states/eV unit cell.

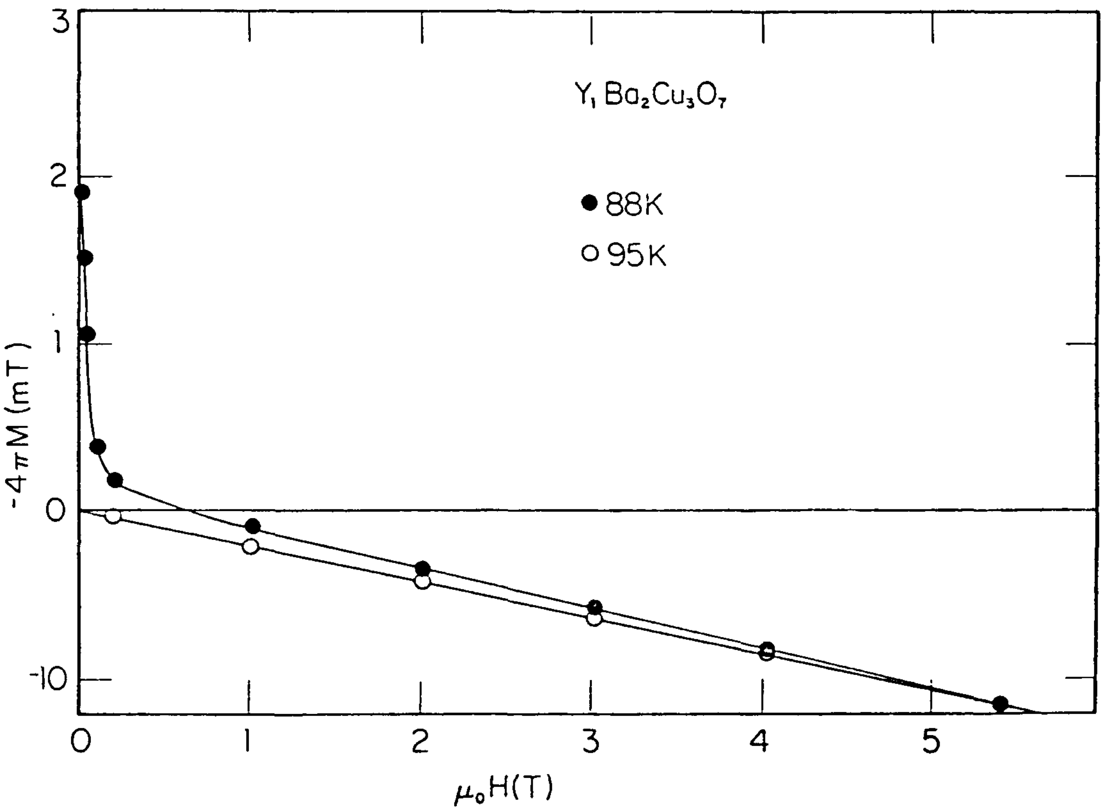

Fig. 3. Reversible magnetization curve shown intersecting the normal state magnetization.

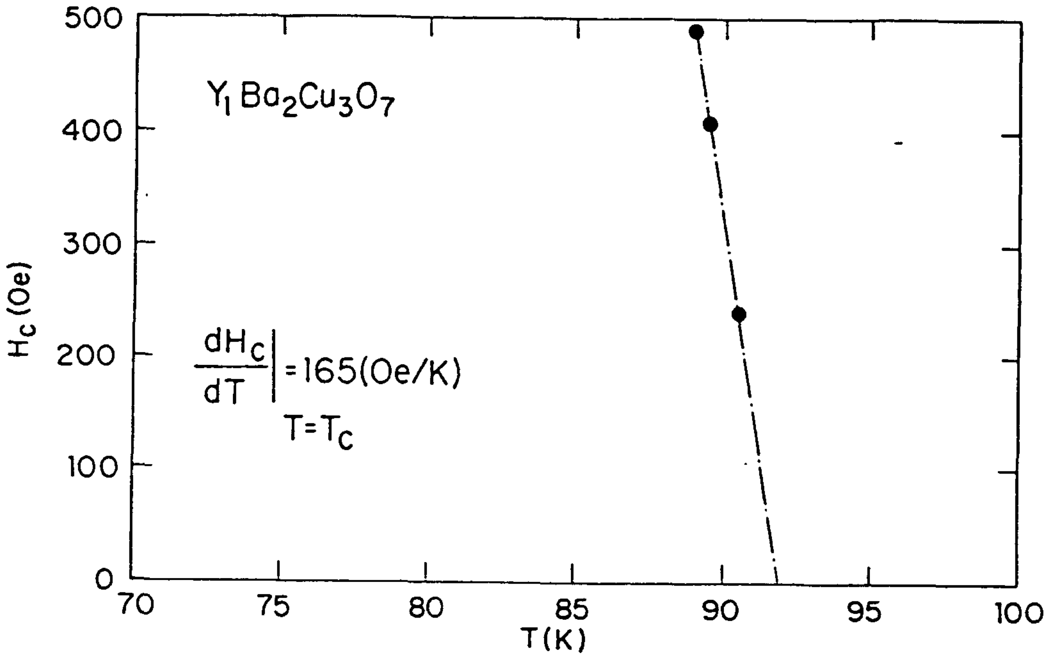

Fig. 4. Thermodynamic critical field.

CONCLUSION

There is a limited range of temperature close to T_C where the magnetization curves are reversible and one can obtain the free energy difference between the superconducting and normal states and thus, the thermodynamic critical field curve. Thermodynamics then give a jump in specific heat of 1.03 J/moleCuK or $(C_n-C_s)/T_c$=11.4 mJ/moleCuK^2. The slope of the thermodynamic critical field curve is found to be very similar to elemental superconductors. The density of states is found to be N(0)=3.4 states/ev unit cell.

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