# Metamagnetism of $Er_2Cu_2O_5$

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The magnetization and magnetostriction of $Er_2Cu_2O_5$ samples, both polycrystalline and single crystals, have been measured. Below $T_N$ this compound is a metamagnet. An $H$-$T$ magnetic phase diagram has been plotted. The results found for the single-crystal sample show that the antiferromagnetism vector is oriented along the $b$ axis of the crystal. Metamagnetic transitions in other $R_2Cu_2O_5$ cuprates (R = Y, Tb, Dy, Ho, Tm, Yb, Lu) have been studied.

If we wish to reach an understanding of the nature of high-temperature superconductivity, it is important to study the properties of not only the high-temperature superconductors themselves but also those of compounds which are similar in crystal structure and chemical composition but which are not superconductors. In the BaO–$R_2O_3$–CuO systems, in which there are some rare-earth high-temperature superconductors ($RBa_2Cu_3O_{7-\delta}$), cuprates $R_2Cu_2O_5$ form with $R$ = Tb–Lu and Y (Ref. 1). These compounds have an orthorhombic crystal structure of the $Ho_2Cu_2O_5$ type (space group $Pna2_1$), in which the tetragonal $CuO_5$ pyramids are connected at their bases (distorted $CuO_4$ squares) in zigzag chains along the $c$ axis.[2]

It was recently established that an antiferromagnetic order arises at low temperatures in the $R_2Cu_2O_5$ compounds.[3-5] The presence of one-dimensional chains of copper suggests that metamagnetic transitions out of an antiferromagnetic state can occur in these compounds in strong fields. We have accordingly carried out measurements of the magnetization and magnetostriction of $R_2Cu_2O_5$ (R = Y, Tb–Lu). The measurements were carried out in most detail for polycrystalline $Er_2Cu_2O_5$ and for single crystals of this compound.

The polycrystalline cuprate samples were synthesized by sintering stoichiometric mixtures of the oxides in air at temperatures of 1000–1050 °C for 48–72 h. The $Er_2Cu_2O_5$ single crystals were grown by slowly cooling molten $Er_2O_3$–BaO–CuO systems from 1200 °C. The measurements were carried out on a crystal with dimensions of $0.1\times0.1\times3$ mm, with long dimension along the $b$ axis, with a mass of 0.2 mg. The magnetization was measured in static magnetic fields up to 50 kOe on a vibration magnetometer. The longitudinal and transverse magnetostriction was measured in pulsed fields with the help of piezoelectric transducers cemented to the sample.

Figure 1 shows magnetization isotherms of polycrystalline $Er_2Cu_2O_5$. At low temperatures the magnetization is seen to increase linearly in weak fields; as the field is raised above a certain critical $H_{cr}$, the magnetization then increases sharply: A metamagnetic transition occurs. At 4.2 K we see a hysteresis in the metamagnetic transition. When the magnetic field is turned off, we observe a remanent magnetic moment. This moment decreases with increasing temperature, and the hysteresis in the transi-

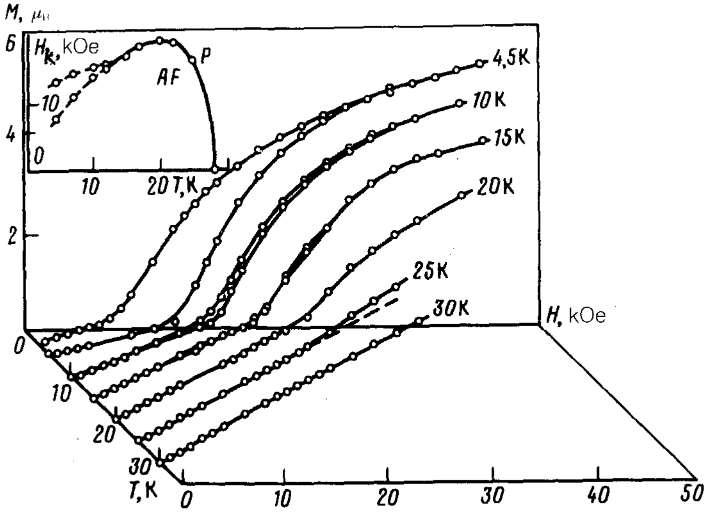

FIG. 1. Magnetization isotherms and phase diagram (the inset) of polycrystalline $Er_2Cu_2O_5$. The dashed lines show the stability boundaries of the paramagnetic (*P*) and antiferromagnetic (*AF*) phases for the first-order phase transition; the solid lines correspond to a second-order phase transition.

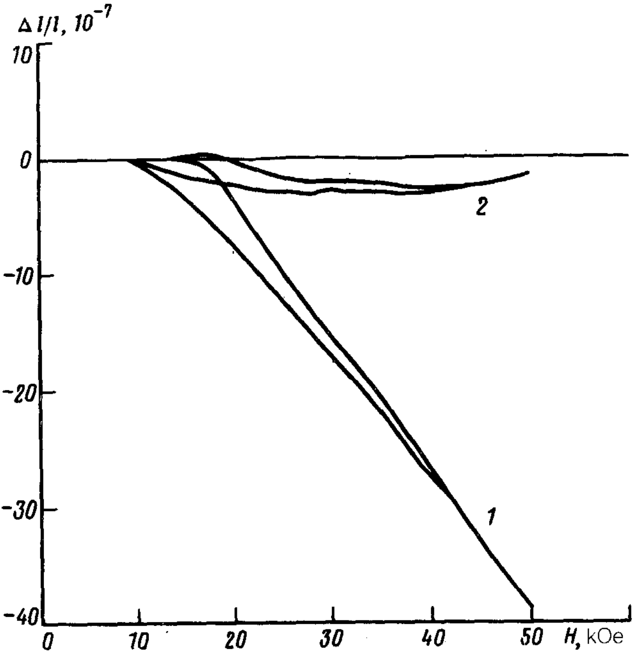

FIG. 2. Anisotropic (1) and bulk (2) magnetostriction of polycrystalline $Er_2Cu_2O_5$ at $T = 5$ K.

tion also becomes less apparent. Above ~15 K the hysteresis disappears; i.e., the metamagnetic transition becomes a second-order phase transition. As the temperature is rasied, the critical field $H_{cr}$ initially increases, goes through a maximum, and then decreases sharply near the Néel temperature $T_N = 28$ K. The magnetic phase diagram found for $Er_2Cu_2O_5$ from the magnetic measurements is shown in the inset in Fig. 1.

The metamagnetic transition is accompanied by anomalies in the magnetostriction (Fig. 2). The magnetostriction is near zero in fields below $H_{cr}$, and it increases sharply at $H > H_{cr}$ (a possible reason for the difference between the critical fields found in the measurements of the magnetization and the magnetostriction is that pulsed fields were used for the measurements of the magnetostriction). We see from this figure that the magnetostriction is basically anisotropic. Our measurements also show that the magnetostriction of the compound with erbium is significantly larger than that in $Y_2Cu_2O_5$. This result is evidence that the magnetostriction of $Er_2Cu_2O_5$ is associated predominantly with the erbium subsystem.

The metamagnetic transition is seen more clearly in the single-crystal measurements (Fig. 3). In contrast with the polycrystalline case, the metamagnetic transition in the single crystal occurs abruptly. The minimum critical field and the maximum range of the abrupt change are observed in the case $H \| b$; in the case $H \perp b$ the change in the magnetization in the field occurs smoothly. In fields $H > H_{cr}$ the magnetic moment tends toward the value of $(20 \pm 2)\mu_B$ per formula unit. Within the experimental error, this figure agrees with the value of $20\mu_B$ which was calculated under the assumption of a collinear orientation of the magnetic moments of $Cu^{2+}$ ($1\mu_B$) and $Er^{3+}$ ($9\mu_B$).

On the basis of these results we can draw a qualitative picture of the magnetic structure of $Er_2Cu_2O_5$. In each chain, the $Cu^{2+}$ ions are ordered in a ferromagnetic

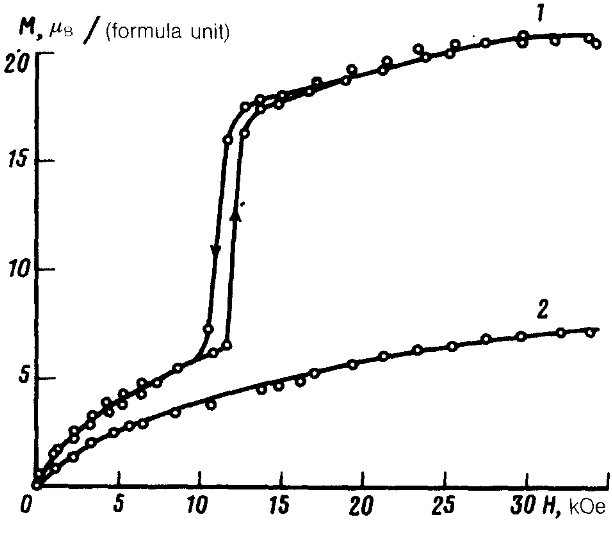

FIG. 3. Magnetization isotherms of an $Er_2Cu_2O_5$ single crystal. 1—$H \| b$; 2—$H \perp b$($T = 7$ K).

fashion, and there is a weak antiferromagnetic interaction between chains. The orientation of the magnetic moments in the chains is collinear with the *b* axis. The magnetic moments of $Er^{3+}$ are ordered in an antiferromagnetic fashion under the influence of an exchange interaction with the copper subsystem. In a field parallel to the *b* axis, the $Cu^{2+}$–$Cu^{2+}$ antiferromagnetic interchain exchange interaction is disrupted, and a ferromagnetic structure arises in both the copper subsystem and the erbium subsystem. This model is supported by measurements of the magnetic susceptibility of $Y_2Cu_2O_5$ (Refs. 3 and 6): The positive value of the paramagnetic temperature, $\theta_p \approx 40$ K, in the Curie-Weiss law $\chi_M = C/(T-\theta_p)$ is evidence of a dominant ferromagnetic interaction in the chains, while the antiferromagnetic order at $T_N = 13$ K is evidence of a weaker negative interaction between chains.

Measurements of the magnetization and magnetostriction of polycrystalline samples of other $R_2Cu_2O_5$ compounds in strong magnetic fields up to 270 kOe showed that metamagnetic transitions are observed in compounds which have both magnetic (Dy, Ho, Tm, Yb) and nonmagnetic (Y,Lu) rare earths. The behavior of the Dy and Ho compounds is analogous to the magnetic behavior of $Er_2Cu_2O_5$, and the critical fields of the metamagnetic transition are approximately the same. In $Tm_2Cu_2O_5$ the critical field of the transition is very weak (below 30 Oe); it is possible that this compound has a spontaneous ferromagnetic moment (the magnitude of this moment is comparable to the magnetization of the compounds with Dy, Ho, and Er at $H > H_{\rm cr}$). The metamagnetic transition in the Y, Yb, and Lu cuprates begins in fields roughly twice that at which it begins in $Er_2Cu_2O_5$; in $Y_2Cu_2O_5$, the transition occurs in two jumps, and in $Y_2Cu_2O_5$ it occurs in three. The magnetic behavior of $Tb_2Cu_2O_5$ is quite different from that of the other cuprates and is not completely clear.

The results which have been reported previously[3–6] and these new results show that the magnetic moments of both the copper and rare-earth subsystems in the $R_2Cu_2O_5$ compounds are localized and that there is a fairly strong exchange interaction between them. This result distinguishes these compounds from the 1-2-3 high-temperature superconductors, in which the magnetic moments of the copper subsystem are largely delocalized, and the coupling of this subsystem with the rare-earth subsystem is negligible. We might add that the magnetic-ordering temperature in these compounds is considerably lower (by more than an order of magnitude) than that in $RBa_2Cu_3O_{7-\delta}$ systems, in which a high-temperature superconductivity has been observed. The nature of this difference is not yet clear; further research is required here.

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