DEPENDENCE OF THE INSULATOR-METAL TRANSITION IN EuO ON MAGNETIC ORDER*

Y. SHAPIRA and S. FONER
Francis Bitter National Magnet Laboratory, MIT, Cambridge, Mass. 02139, USA

T.B. REED
Lincoln Laboratory, MIT, Lexington, Mass. 02173, USA

and

H. BIRECKI and H.E. STANLEY
Department of PHysics, MIT, Cambridge, Mass. 02139, USA

Received 22 August 1972

The Hall coefficient in an EuO sample which exhibited an isulator-metal transition was measured at $T \approx 4T_c$ in fields up to 150 kOe. The results indicate that the activation energy does not vary linearly with magnetization, contrary to the conclusion of Penney et al.

Recently Penney et al. concluded that the activation energy of insulator-metal transition in EuO varies linearly with the magnetization [1]. In this letter we present data which disagree with this conclusion.

The resistivity ρ of some EuO samples decreases by many orders of magnitude between the Curie temperature ($T_c = 69$K) and 50K [1, 2]. This "insulator-metal transition" is due primarily to a change in the carrier concentration n, although a change in the mobility μ may be present. A model which explains the insulator-metal transition was proposed by Oliver et al. [2] and was modified by the group at IBM [1]. In this model, above ~50K, n is proportional to $\exp(-\Delta/kT)$, where Δ is an activation energy which depends on magnetic order. At $T \gg T_c$, Δ assumes a constant value, Δ_0, and $\rho \sim \exp(\Delta_0/kT)$.

Recently Penney et al. [1] considered two possible dependences of Δ on magnetic order: 1) Δ varies linearly with the reduced magnetization (long range order parameter) $\sigma = \langle S \rangle / S$, i.e.,

$$\Delta = \Delta_0(1 - a\sigma) , \tag{1}$$

where a is a constant; 2) Δ varies linearly with the nearest-neighbor two-spin correlation function (short range order parameter) $\eta = \langle \boldsymbol{S}_1 \cdot \boldsymbol{S}_2 \rangle / S^2$, i.e.,

$$\Delta = \Delta_0(1 - b\eta) , \tag{2}$$

where b is a constant. From their analysis of $\rho(T)$ at $T < T_c$ Penney et al. concluded that Δ obeys eq. (1) but not eq. (2). However, in this analysis the possibility that μ depends on T was not taken into account. In addition, agreement of the resistivity data at

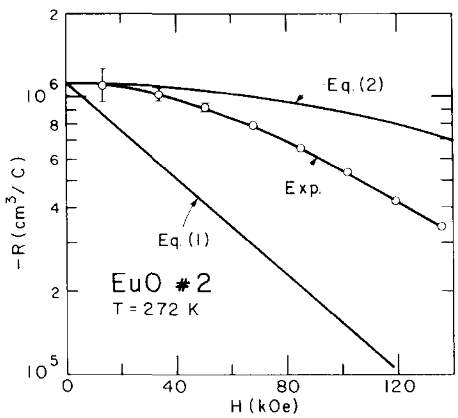

Fig. 1. H-dependence of the Hall coefficient at 272 K (semi-log scale). The theoretical curves were calculated from eqs. (1) and (2) using the magnetic susceptibility of this sample, and $\Delta_0 = 0.32$ eV, $a = 1.39$, $b = 1.5$, $\eta(H) - \eta(0) = 1.08\,\sigma^2$

* Work supported by NSF, by the Department of the Air Force, and by ONR.

20 kOe with eq. (1) was obtained by assuming the largest possible demagnetizing factor, 4π. This assumption is questionable.

In the present work the dependence of Δ on magnetic order was studied by measuring the Hall coefficient $R = |1/ne|$ near room temperature ($T \approx 4T_c$) in magnetic fields up to 150 kOe. These measurements provide a meaningful test of eqs. (1) and (2) because: a) at $T \approx 4T_c$ these equations predict vastly different behaviors for R versus H, and b) the analysis of the results at $T \approx 4T_c$ is not sensitive to mobility changes or to demagnetization corrections.

At $T \approx 4T_c$, $\sigma \approx 0.15$ at 150 kOe and σ is proportional to H at lower fields. Molecular field theory gives $\eta = \sigma^2$. A better estimate of $\eta(H)$ was obtained from a calculation based on a high-temperature series expansion. Our calculation showed that although η does not vanish at $H = 0$, the H-induced increase in η at $4T_c$ is well described by $\eta(H) - \eta(0) = 1.08\,\sigma^2$. At 150 kOe, $\sigma^2 \approx 0.02 \ll \sigma$. These considerations show that eq. (1) leads to a linear dependence of $\log R(H)$ on H, whereas eq. (2) leads to a quadratic dependence. Resistivity data below T_c give values for a and b, in eqs. (1) and (2), which are roughly equal. With these values for a and b, eq. (1) predicts a much larger variation of R with H at $T \approx 4T_c$ than eq. (2), since $\eta(H) - \eta(0) \ll \sigma(H)$.

Measurements were carried out on a single crystal EuO sample which exhibited a clear insulator-metal transition. For this sample the T-dependence of ρ at $T \gg T_c$ gave $\Delta_0 = 0.32$ eV. Analysis of $\rho(T)$ below T_c, using the procedure described in [1] and assuming the validity of eq. (1), gave $\Delta_0 = 0.28$ eV and $a = 1.39$. A value $b \approx 1.5$ for the coefficient in eq. (2) was estimated from the value of η at the onset of the insulator-metal transition (where $\Delta \to 0$).

Experimental results for $R(H)$ versus H at 272 K are shown in fig. 1, together with the H-dependence of $R(H)$ calculated from eqs. (1) and (2) using $\Delta_0 = 0.32$ eV. The experimental data lie between the two calculated curves. Moreover, analysis shows that $\log[R(H)/R(0)] \sim H^r$ with $r = 1.8$, which is between $r = 1$ [eq. (1)] and $r = 2$ [eq. (2)]. These conclusions remain unchanged if a value $\Delta_0 = 0.28$ eV is used instead of 0.32 eV. A similar behavior of $R(H)$ was also observed at 288 K. We therefore conclude that near $4T_c$ the dependence of Δ on magnetic order is intermediate between eq. (1) and eq. (2).

References

[1] T. Penny, M.W. Shafer and J.B. Torrance, Phys. Rev. B5 (1972) 3669, and refererence therein.
[2] M.T. Oliver et al., Phys. Rev. B5 (1972) 1078.