MAGNETORESISTANCE OF POLYCRYSTALS AND ITS SIZE EFFECT

Yu.A. Dreizin and A.M. Dykhne
Submitted 14 July 1971
ZhETF Pis. Red. 14, No. 2, 101 - 105 (20 July 1971)

1. Introduction. It is well known [1] that in metals with open Fermi surfaces in strong magnetic fields $\vec{H}$ ($\gamma \equiv \nu/\omega_H \ll 1$, ν - collision frequency, $\omega_H = eH/mc$) the asymptotic form of the conduction tensor depends on the orientation of the crystal relative to the magnetic field. Namely, if open trajectories contribute to the conductivity at a given critical orientation, then the conductivity across the magnetic field is "not magnetized," i.e., it does not decrease with increasing H, and has in general the same order of magnitude as the conductivity σ_0 along the magnetic field. On the other hand, if the orientation is such that there are no open trajectories, then the transverse components of the conductivity tensor decrease with increasing field, $\sigma \sim \sigma_0\gamma^2$. As a result, a polycrystalline sample consisting of randomly oriented crystallites is a medium with anisotropic and strongly inhomogeneous conductivity. This raises the question of finding the effective conductivity of such a medium, connecting the current density averaged over the sample with the average electric field; we see that the effective conductivity can differ greatly from the average conductivity of an inhomogeneous medium. We have assumed the crystallites to be macroscopic (the electron mean free path is small compared with the characteristic dimension a of the crystallites). For concreteness we consider the case of a metal with such a Fermi surface, that there exists a finite albeit small fraction c of magnetic field directions at which there are open trajectories (such a situation occurs, e.g., in gold, where $c \sim 3 \times 10^{-2}$ [2]). Accordingly, the fraction of the crystallites with non-magnetized conductivity is equal to c. Finally, the last remark concerns the antisymmetrical part $\hat{\sigma}^a$ of the conductivity tensor, which determines the Hall current. It can be shown that the antisymmetrical part of the effective conductivity tensor is determined simply by averaging $\hat{\sigma}^a$. In addition, allowance for $\hat{\sigma}^a$ is immaterial for the determination of the symmetrical part of the effective conductivity tensor, for when this problem is solved it can be assumed that the conductivity tensor of the medium is symmetrical.

2. Effective conductivity of bulky sample. Figure 1 illustrates the polycrystalline medium under consideration. The crystallites in which (owing to the open trajectories) the transverse conductivity does not decrease with increasing H will be called for brevity "singular"; they are shown shaded in the figure. The remaining mass of the crystallites forms a "background" in which the transverse conductivity is small in strong fields, $\sigma \sim \sigma_0\gamma^2$. We consider first the case of very strong fields (the criterion will be written out below) when the transverse conductivity of the "background" can be completely neglected. It is clear, however, that in this case the effective transverse conductivity of the polycrystalline medium will be different from zero, since current can flow in the manner illustrated in Fig. 1, in the direction of the average electric field $\langle\vec{E}\rangle$ ($\langle\vec{E}\rangle \perp \vec{H}$) through the singular crystallites and flow over from one singular crystallite to another through the "background" along the magnetic field. Let us estimate the conductivity resulting from such a mechanism. The average distance L in the $\vec{H}$ direction between two "neighboring" singular crystallites (through which the current line goes in succession) can be estimated at

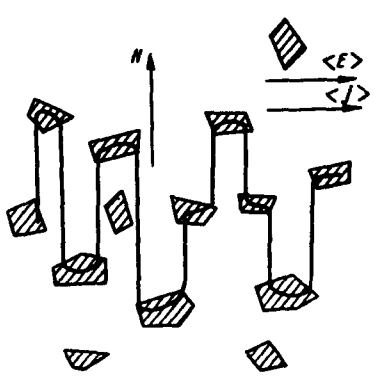

Fig. 1

$$L \sim 1/na^2 \sim a/c, \qquad (1)$$

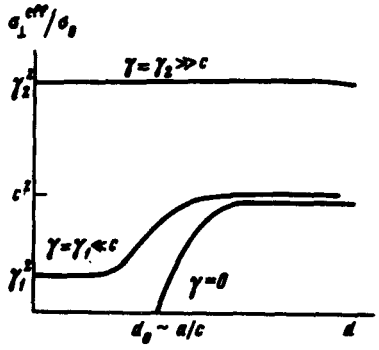

Fig. 2

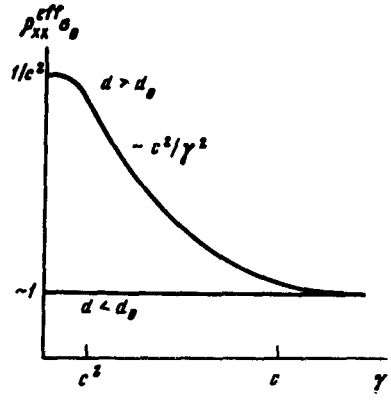

Fig. 3

where $n \sim c/a^3$ is the number of singular crystallites in cm^3. Since the neighboring singular crystallites are shifted in the direction of $\langle\vec{E}\rangle$ by a distance on the order of a, the potential difference between them is $\Delta\phi \sim \langle E\rangle a$. On the other hand, it can be estimated also as $\Delta\phi \sim E_z L$, where E_z is the order of magnitude of the z-th component of the electric field (the z axis is along $\vec{H}$; we emphasize that there is no average electric field in the z direction). Comparing these estimates we obtain with allowance for (1) $E_z \sim c\langle E\rangle$. The current density $j_z \sim \sigma_0 E_z \sim \sigma_0 c\langle E\rangle$. We are interested in $\langle j\rangle$ - the average current density ($\langle\vec{j}\rangle$ is directed along $\langle\vec{E}\rangle$). We note that $j_\perp$ differs from zero only in the singular crystallites, in which $j_\perp \sim j_z \sim \sigma_0 c\langle E\rangle$. On the other hand, the average current density is smaller by a factor c, since the fraction of these crystallites is c. From this we obtain $\langle j\rangle \sim \sigma_0 c^2 \langle E\rangle$ or

$$\sigma_\perp^{eff} \sim \sigma_0 c^2. \qquad (2)$$

Competing with the described conductivity mechanism is the usual mechanism, wherein the main current $j_\perp$ flows through the "background." For this current $\sigma_\perp \sim \sigma_0 \gamma^2$. Comparing this with (2), we find that (2) is valid when $\gamma \lesssim c$. When $1 \gg \gamma \gtrsim c$ we have $\sigma_\perp^{eff} \sim \sigma_0 \gamma^2$.

3. Size effect. If the sample has a finite dimension d in the direction of the magnetic field, then formula (2) is valid (for $\gamma \ll c$) only in the case when $d \gg L$. Indeed, to establish the mechanism of current flow described above it is necessary that the projections of the singular crystallites on a plane perpendicular to $\vec{H}$ overlap sufficiently well. On the other hand, if the thickness of the sample is insufficient for this, $d \ll L$, then $\sigma_\perp^{eff} \sim \sigma_0 \gamma^2$ also when $\gamma \ll c$. Figure 2 shows qualitatively the dependence of $\sigma_\perp^{eff}$ on d. When $\gamma = 0$ the change of the conductivity with changing thickness has the character of a phase transition. The effective conductivity is equal to zero when $d < d_0 \sim L$, and differs from zero when $d > d_0$. The asymptotic value $\sigma_\perp^{eff} \sim \sigma_0 c^2$ is also reached at thicknesses on the order of L. When $0 \neq \gamma \ll c$ the transition becomes smoothed out and is finally washed out at $\gamma \gtrsim c$.

4. Possibility of experimentally observing the size effect. In experiment one usually measures the transverse component of the resistivity tensor ρ_{xx} (the current flows along the long dimension of the sample). For a thick sample

($d > d_0$) the effective conductivity tensor has the following components (the symbol eff is omitted; for σ_{xx} we write down an interpolation formula that matches the regions $\gamma \ll c$ and $\gamma \gg c$): $\sigma_{xx} = \sigma_{yy} \sim \sigma_0(\gamma^2 + c^2)$; $\sigma_{xy} = -\sigma_{yx} \sim \sigma_0\gamma$; $\sigma_{zz} \sim \sigma_0$, the remaining components are equal to zero. Inverting the tensor σ, we obtain for ρ_{xx}:

$$\rho_{xx} = \frac{\sigma_{yy}}{\sigma_{xx}\sigma_{yy} + \sigma_{xy}^2} \sim \sigma_0^{-1} \frac{\gamma^2 + c^2}{(\gamma^2 + c^2)^2 + \gamma^2}. \qquad (3)$$

A plot of this function is shown in Fig. 3. $\rho_{xx} \sim \sigma_0^{-1}$ when $c \ll \gamma \ll 1$, $\rho_{xx} \sim \sigma_0^{-1}c^2/\gamma^2$ when $c^2 \ll \gamma \ll c$, and $\rho_{xx} \sim \sigma_0^{-1}/c^2$ when $\gamma \lesssim c^2$. For a thin sample ($d < d_0$) we have $\sigma \sim \sigma_0\gamma^2$ in the entire region $\gamma \ll 1$, and $\rho_{xx} \sim \sigma_0^{-1}$. Thus, even in the region $\gamma \lesssim c$ the resistance increases sharply (by $(c/\gamma)^2$ times) when the sample thickness increases from $d < d_0$ to $d > d_0$. In conclusion we present approximate estimates. For $H \sim 10^5$ G and a free path $\sim 10^{-2}$ cm we have $\gamma \sim 10^{-2}$. If the crystallite dimension is $a \sim 3 \times 10^{-2}$ cm and $c \sim 3 \times 10^{-2}$, then the size effect will be observed at thicknesses $d_0 \sim a/c \sim 1$ cm. One can expect an increase of the resistance by a factor $(c/\gamma)^2 \sim 10$ times on going from $d < d_0$ to $d > d_0$.

[1] I.M. Lifshitz and M.I. Kaganov, Usp. Fiz. Nauk 87, 389 (1965) [Sov. Phys.-Usp. 8, 805 (1966)].
[2] Yu.P. Gaidukov, Zh. Eksp. Teor. Fiz. 37, 1281 (1959) [Sov. Phys.-JETP 10, 913 (1960)].

NUCLEAR MAGNETIC RESONANCE IN CERTAIN ORTHOFERRITES

N.M. Kovtun, E.E. Solov'ev, A.A. Shamyakov, and V.A. Khokhlov
Donets Physico-technical Institute, Ukrainian Academy of Sciences

Submitted 14 June 1971
ZhETF Pis. Red. 14, No. 2, 105 - 107 (20 July 1971)

At the present time, signals of nuclear magnetic resonance on Fe^{57} nuclei in orthoferrites were observed only with the aid of a superregenerator in single-crystal yttrium orthoferrite grown by the hydrothermal method with spontaneous crystallization [1]. As to NMR in hyperfine fields on the nuclei Y^{89}, it follows from the literature that it has not been observed at all in any ferromagnetic and antiferromagnetic compound.

We present here a brief report of observation of NMR of Fe^{57} in $YFeO_3$, $TmFeO_3$, and $Y_{1-x}La_xFeO_3$, and also NMR of Y^{89} in $YFeO_3$ and $Y_{1-x}La_xFeO_3$.

The samples were polycrystalline yttrium and yttrium-lanthanum orthoferrite obtained by the usual ceramic technology, and single-crystal thulium orthoferrite grown by crucible-less zone melting with optical heating.

The search for the NMR signals was carried out with the aid of a semiautomatic spin-echo spectrometer with exciting-pulse durations $\tau_1 = 1$ μsec and $\tau_2 = 1$ μsec. To exclude the influence of the transverse and longitudinal relaxation, the interval between the pulses was chosen to be 50 μsec, and the repetition frequency was 29 GHz. The signals were registered with a stroboscopic integrator. All the measurements were carried out at 77°K.