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# MINIMUM ELECTRIC RESISTIVITY OF AN ANTIFERROMAGNETIC METAL (Cr)

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It is known that the resistivity of many impurity-containing metals has at low temperatures an anomalous behavior which is manifest in the presence of a minimum on the R(T) curve. This was observed experimentally in such weakly-magnetic metals as Ag, Au, Cu, Mg, Zn, Mo, and Al [1-6] with small amounts of definite metallic impurities added. Many authors connect this minimum with the presence of a local magnetic moment.

The resistivity minimum has recently been given a theoretical explanation from which it follows that the minimum arises in negative exchange interaction between the conduction electrons and the impurity atoms as a result of the addition of the ordinary electric resistivity, which decreases with temperature [7,8], as well as in positive exchange interaction [9].

We report here observation of a minimum in the resistivity of a metal with magnetic ordering, such as chromium, in its antiferromagnetic state.

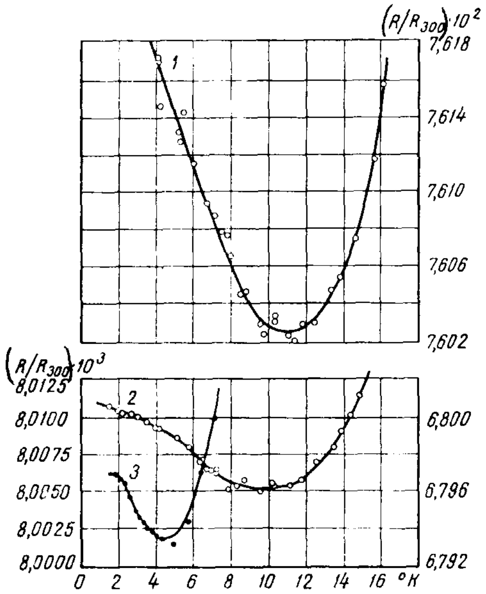
The phenomenon was discovered and investigated in chromium samples of varying purity. A measure of the latter was the residual resistivity $R_{1.5^\circ K}/R_{300^\circ K}$, equal to $7.6 \times 10^{-2}$, $6.8 \times 10^{-3}$, and $8 \times 10^{-3}$ respectively ($R_{1.5^\circ K}$ - resistivity of samples at 1.5°K, $R_{300^\circ K}$ - at 300°K). All investigated chromium samples had minima of resistivity below 15°K.

Figure 1 shows the measurement data for three samples of differing purity. For the most contaminated sample (curve 1 - ordinate scale on right) the resistivity minimum occurs at the highest temperature (~10°K), and its depth is only ~0.07%. A minimum of like depth is observed also for the purest chromium (curve 3 - ordinate scale on left), although the temperature of the minimum is lower (~5°K).

Neither the depth of the minimum nor its temperature changed after the samples were annealed in vacuum better than $10^{-7}$ mm Hg at ~1300°C.

Preliminary measurements of the minimum electric resistivity of chromium with residual resistivity $\sim 8 \times 10^{-3}$ in a longitudinal magnetic field of ~30 kOe have shown that the minimum does not disappear in this field. This is unusual, for it is known, for example, that in other metals the minimum of resistivity vanishes in fields 10 - 20 kOe [4,5].

Unfortunately there are still no quantitative data on the impurity composition of the samples, but it can be noted that even the purest one contained 0.01% iron, $6 \times 10^{-3}$% nickel,



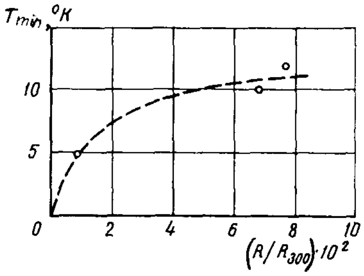


Fig. 2. Temperature of minimum resistivity ($T_{min}$, °K) vs. residual resistivity. R -- resistivity at 1.5°K, $R_{300}$ -- at 300°K.

Fig. 1. Temperature dependence of the relative resistivity $R/R_{300}$ (R -- resistivity at given temperature, $R_{300}$ -- at 300°K).

and ~5 x $10^{-4}\%$ manganese.

If we use the residual resistivity for a qualitative estimate of the impurities, then the dependence of the minimum temperature on the residual resistivity will have for the chromium samples on hand the form shown by the smooth curve of Fig. 2. It is interesting that the curve has exactly the same form as for gold [1].

We call attention to the fact that the minimum resistivity was observed for an antiferromagnetic metal (chromium) with large internal magnetic field; this may be the reason why an external field of 30,000 Oe was still ineffective.

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# SINGULARITIES OF THE TEMPERATURE DEPENDENCE OF ELECTRIC CONDUCTIVITY OF ALUMINUM AT HELIUM TEMPERATURES

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It is still unclear [1] why the power-law dependence $T^5$, obtained from highly simplified theoretical considerations, is in good agreement with results of investigation of the temperature dependence of electric resistivity of nonmagnetic non-transition metals. It is perfectly possible that this is connected with the insufficient accuracy with which the resistivity is measured, especially at low temperatures where deviations from the $T^5$ law are to be properly expected, since the roles of the different electron scattering mechanisms become comparable.

On the basis of the experimental data [2], an empirical formula was proposed for aluminum [3] in the form of a superposition of the contributions of the electron-electron and electron-phonon scattering:

$$\delta_\infty(T) = (1.98 \times 10^{-2}\ [\mathrm{deg}^{-2}]T^2 + 4.34 \times 10^{-6}\ [\mathrm{deg}^{-5}]T^5) \times 10^{-5} \qquad (1)$$

The index ∞ denotes that expression (1) was obtained from data for bulky samples. This is a reasonable dependence, for it yields for the contribution of the electron-electron interaction to the electric resistivity at helium temperatures a value (~10%) which does not contradict estimates obtained from data on the infrared absorption [4]. If expression (1) is correct, then at helium temperature $\delta_{4.2}$ differs from $\delta_0$ by $10^{-6}$ ($\delta_T = R_T/R_{273°K}$, $\delta_0 = R_0/R_{273°K}$, where $R_0$ is the residual resistivity of the sample, $R_T$ the resistivity at the temperature of the experiment, and $R_{273°K}$ the resistivity at 0°C). An exact measurement of this quantity makes it necessary, in the case of bulky specimens of reasonable length, to measure resistance changes of the order of $\sim 10^{-11}$ ohm.

We have investigated the temperature dependence of the resistivity of aluminum by a procedure similar to that described in [5], which affords the required measurement accuracy (the voltage sensitivity of the apparatus is $10^{-11}$ - $5 \times 10^{-12}$ V). We present here the first results.

The investigated metal was aluminum, whose carrier Fermi surface is either closed or, if open, contains narrow necks. The temperature-dependent part of the resistivity of such metals, if observed, cannot be explained at low temperatures solely in terms of electron-phonon collisions with umklapp [4].

Single-crystal samples of varying (but sufficiently high) purity can be regarded as bulky. Therefore their residual resistance is connected only with scattering of electrons by microscopic defects, such as impurities. The transverse dimension of the samples was 5 - 10 mm and was appreciably larger than $\ell_{ei}$ (the mean free path of electron scattering by impurities).