THE INFLUENCE OF PLASTIC DEFORMATION ON THE ANOMALOUS BEHAVIOR OF THE RESISTANCE OF GOLD AT LOW TEMPERATURES

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WE have noted earlier[1] that the depth of the minimum of the resistance r_T vs. temperature curve for gold is decreased when the measurement is performed in a constant magnetic field, and for some value of the field H_k becomes equal to zero. An investigation of the dependence of the Hall emf on the magnitude of the magnetic field and also a measurement of the magnetic susceptibility have shown that for a field equal to H_k the Hall constant and the diamagnetic susceptibility of the samples investigated increase discontinuously.[2]

For a further investigation of the causes influencing the resistance minimum of gold, we performed experiments to determine the influence of elastic and plastic deformations both on the depth of the minimum and on the value of the "critical" field H_k. To study the influence of elastic deformations, we experimented on some samples of gold possessing a resistance minimum. The measurement proceeded with a uniform compression, produced by freezing water in a beryllium-bronze bomb[3] in which the gold sample was placed. A measurement of the dependence of $(r_{1.4} - r_{min})/r_{min}$ at pressures of $p = 0$ and $p = 1600$ atmos in the temperature range from 4.2 to 1.4°K showed that under a uniform compression the depth of the minimum decreased slightly by an amount which is less than the limits of the experimental accuracy, while the resistivity also changes slightly.

To investigate the influence of plastic deformations on the behavior of the resistivity curves we took two sets of experiments.* In the first experiments the deformation of the specimen was produced at liquid-helium temperature. To produce the deformation we used a special press in which a wire prepared from the gold batch Au-1 or Au-6 (length ≈ 9 mm, diameter ≈ 0.4 mm) was squashed between two horizontal plates of agate. The degree of deformation was estimated from the magnitude of the relative change in the resistivity $\alpha = \rho_{4.2}^{def}/\rho_{4.2}^{0}$ produced by the deformation at 4.2°K. In Fig. 1 we give the results of the measurements.

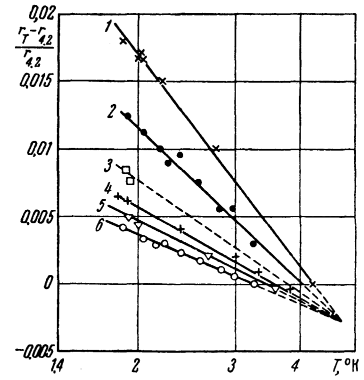

FIG. 1. Specimen Au – 1. Dependence of the anomalous increase of the resistivity on the temperature (the abscissa axis is logarithmic). Values of α: 1) 1, 2) 1.8, 3) 2.5, 4) 3.9, 5) 6.2, 6) 8.

The deformations obtained at liquid-helium temperature were relatively small (wire of 0.4 mm diameter was squashed into a plate not less than 0.20 mm thick).

To investigate the influence of stronger deformations we performed experiments with wires deformed at room temperature in a hydraulic press. In that case the degree of deformation was estimated from the quantity $\beta = r_{295}/r_{4.2}$. In Figs. 2 and 3 the results are given of the measurements of the depth of the minimum and of H_k for deformed samples of Au-1 and Au-6. Analogous measurements were performed on a number of other gold samples.

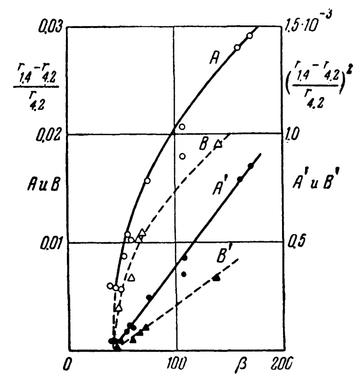

FIG. 2. Dependence of the depth of the resistivity minimum on deformation: ●, ○) specimen Au-1; ▲, △) specimen Au-6.

From all results given it is clear that the depth of the minimum and the magnitude of the "critical" field depend strongly on the deformation. From Figs. 2 and 3 it follows that for a well determined value of the deformation the depth of the minimum tends to zero and the critical field tends to infinity. If the deformed specimens are annealed for 30 minutes at a temperature of 800 to 900°C the anomalous properties of the specimens are restored. One must note that within the limits of

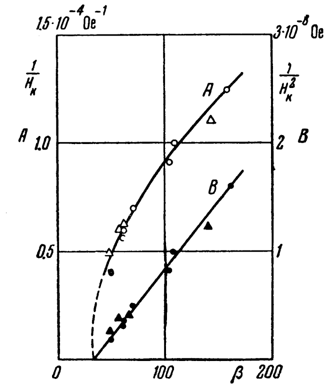

FIG. 3. Dependence of the critical field on the deformation: ●, o) specimen Au-1; ▲, △) specimen Au-6.

the experimental accuracy the value of T_{min} is not changed by the deformation and lies for all specimens in the range 4 to 6°K. Earlier we have already reported[1] that specimens prepared from Au-4 do not show a resistance minimum. A spectral analysis performed on these samples showed that gold of the two batches (both Au-1 and Au-4) does not differ essentially in their impurity contents. On the basis of the data given in the present paper, it was assumed that specimens prepared from Au-4 after careful annealing would also, like those from Au-1, have a minimum in the r(T) curve. Experiments performed by us confirmed this assumption.

Comparing all results obtained we can conclude that the cause responsible for the appearance of a resistance minimum is the scattering of conduction electrons by impurities of some well defined elements. A decrease of the mean free path of the conduction electrons (for instance, due to the deformation) leads to a decrease of the probability for scattering of the electrons by those impurities, and as a result the anomalous properties also disappear. From this point of view, the crystal boundaries and the grain size are not responsible for the appearance of the resistance minimum.

In conclusion we consider it a pleasant duty to express our gratitude to academician P. L. Kapitza for a discussion of the results obtained.

*We should remark Schmitt[4] has noted the influence of deformation on the behavior of the resistance curves in the case where a minimum is present for copper.

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THE SCATTERING OF SPIN 3/2 PARTICLES BY A COULOMB FIELD

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IN studying the spin of new particles it may be of interest to describe how their interaction with an electro-magnetic field depends upon their spin. This spin dependence appears clearly in such phenomena as Compton scattering, bremsstrahlung, and pair production of particles of spin 0, 1/2, 1, and 3/2 and has been considered by a number of authors.

In the present note we consider the scattering of particles of spin 3/2 by the Coulomb field of a nucleus.

The matrix element for the process looks as follows in the Born approximation:

$$\mathcal{M} = -e\int \overline{B}^i(x)\, A_k(x)\, \gamma_k B^i(x)\, d^4x,$$

where $B^i(x)$ is the spin vector describing the particles of spin 3/2, and obeys the following equation and subsidiary conditions:

$$(\gamma_k\partial/\partial x_k + M)\, B^i(x) = 0, \quad \gamma_i B^i = 0, \quad \partial B^i/\partial x_i = 0;$$

$A_k(x)$ is the 4-potential describing the nuclear field [for a static field, $A(x) = (0, 0, 0, A_4(\mathbf{x}))$]. In the p representation

$$\mathcal{M} = -2\pi e a_4(\mathbf{q})\, \overline{B}^i(p_f)\, \gamma_4 B^i(p_i)\, \delta(E_f - E_i), \quad \mathbf{q} = \mathbf{p}_f - \mathbf{p}_i.$$

Making use of the following formula in summing over the polarizations

$$\sum_m [B^i_m(p)]_\nu [\overline{B}^k_m(p)]_{\nu'} = (1/6E_pM)\,[(M - i\gamma p)(2p_ip_k/M + 3M\delta_{ik} + i\gamma_ip_k - i\gamma_kp_i - M\gamma_i\gamma_k]_{\nu\nu'}$$

(ν, ν' are spinor indices) we obtain the differential cross section