Low-Field Magnetoresistance of Copper and Silver Single Crystals

W. Neubert

Physikalisch-Technische Bundesanstalt, Braunschweig

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Measurements of the magnetoresistance coefficients at 4.2 °K in single crystals of copper and silver are reported. The experimental values are found to agree reasonably well with the results of numerical calculations using a model based on Roaf's analytical representation of the Fermi surface.

For a cubic crystal in a sufficiently weak magnetic field, the magnetoresistance can be described by a set of 3 coefficients b', c', and d' which are defined by the following series expansion [1, 2] of the electric field $\boldsymbol{E}$ in powers of the magnetic Induction $\boldsymbol{B}$:

$$\boldsymbol{E} = \varrho_0 \boldsymbol{J} + a(\boldsymbol{J} \times \boldsymbol{B}) + \frac{1}{\varrho_0}[b' B^2 \boldsymbol{J} + c'(\boldsymbol{B}\,\boldsymbol{J})\boldsymbol{B} + d' \boldsymbol{M} \cdot \boldsymbol{J}]. \quad (1)$$

$\boldsymbol{J}$ is the current density, ϱ_0 the zero magnetic field resistivity, a the Hall coefficient, and $\boldsymbol{M}$ a second rank tensor which, when referred to the cubic axes, is diagonal and has the components B_1^2, B_2^2, B_3^2.

The magnetoresistance coefficients were determined experimentally at 4.2 °K from the change of resistance in transverse and longitudinal magnetic fields. Results are shown in Fig. 1 and Fig. 2. The axes of the rod shaped crystals examined were parallel to the [110] direction which is the most favourable orientation for determining b', c', and d'. The resistance ratio $R_{293\,°K}/R_{4.2\,°K}$ ranged from 150 to 300. The small voltage drop across a sample was measured by means of a superconducting modulator [3].

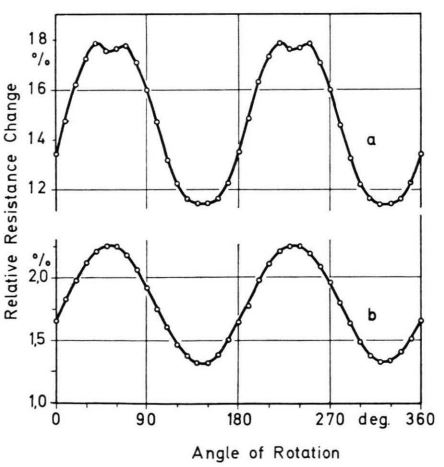

Fig. 1. Relative resistance change of an Ag-crystal in a transverse magnetic field versus angle of rotation around the [110] axis at $B = 0.28$ Vs/m² ≙ 2800 Gauss (curve a) and $B = 0.08$ Vs/m² ≙ 800 Gauss (curve b). Note different scale.

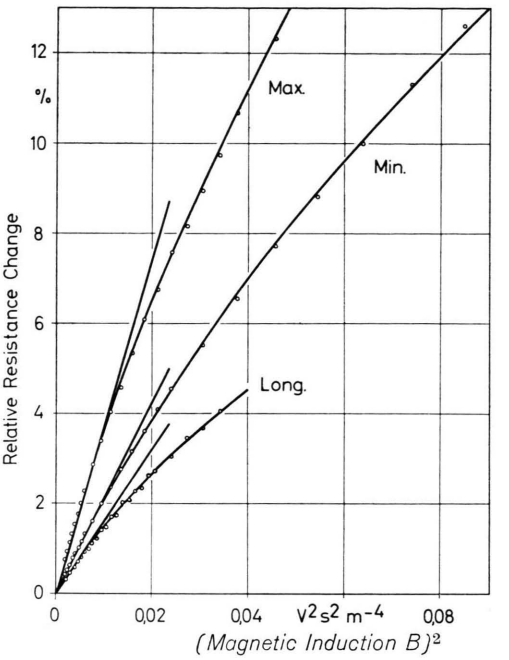

Fig. 2. Relative resistance change of the same Ag-crystal as in Fig. 1 versus B^2 in a longitudinal magnetic field and for 2 orientations in a transverse magnetic field corresponding to minimum and maximum of curve b in Fig. 1.

The appearance of higher order harmonics in curve a of Fig. 1 and the departure from linearity in Fig. 2 indicate that Eq. (1) does not hold for the higher values of B in the diagrams shown. Therefore, for every crystal, the coefficients b', c', and d' were derived from a transverse rotational diagram at $B \leqq 0.1$ Vs/m² and from the slope of the longitudinal field dependence curve at the origin.

For comparison, the coefficients b', c', and d' were also calculated using a model based on a Fourier series representation of the Fermi surface [4] as derived from measurements of the De Haas–Van Alphen effect and the anomalous skin effect. In addition, this Fourier expansion was deemed a fairly good approximation to the band structure near the Fermi level. The scattering processes were assumed to be describable by an isotropic relaxation time.

The magnetoresistance coefficients are listed in Table 1. The Arabic numerals following the chemical symbols label the samples used in the experiments while the Roman numerals specify the Fourier series used [4] for the model calculations. In the last two lines of Table 1, the ratios c'/b' and d'/b' are listed. These values may be considered as a measure of the anisotropy of the magnetoresistance. b' was chosen as reference value for it does not depend on the crystal orientation.

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	experimental				theoretical				
	Cu1	Cu2	Ag1	Ag2	CuIV	CuVI	AgIV	AgVI	
b'	0,52	0,46	0,55	0,71	0,72	1,14	1,07	1,57	$\cdot 10^{-20}$
$-c'$	0,51	0,48	0,54	0,70	0,73	1,17	1,00	1,05	m^6/A^2s^2
d'	0,95	0,83	0,64	1,01	1,27	1,52	1,47	1,44	
$-c'/b'$	0,98	1,03	0,99	0,98	1,01	1,02	0,94	0,67	
d'/b'	1,84	1,79	1,17	1,41	1,77	1,33	1,38	0,92	

Table 1.

The experimental and theoretical results agree remarkably well, especially for copper, as far as the anisotropy of the magnetoresistance is concerned although the band structure is not sufficiently well known. The absolute values of the magnetoresistance coefficients, however, agree within a factor of 2 only. There is a certain discrepancy between the absolute values observed for different samples, indicating that KOHLER's rule does not hold strictly. This may arise from the assumption of an isotropic relaxation time being not fully justified. However, there is also experimental evidence that the local resistivity varies to some extent within the crystal leading to improper absolute values but leaving the ratios unaffected to the first order approximation. For the two silver crystals, even these ratios differ appreciably. The reason is, probably, that the condition of a low magnetic field is less well satisfied than for the copper crystals.

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Polarization of 15.85-MeV Neutrons Scattered by Carbon

G. MACK and G. MERTENS

Physikalisches Institut der Universität Tübingen, Deutschland

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Polarization measurements for elastic and inelastic scattering of neutrons from nuclei are of considerable interest for the understanding of nucleon-nucleus interaction and of nuclear reactions. Especially at energies above 10 MeV, where compound elastic effects are small, the nuclear optical model is suited to describe nucleon polarization very well. But because of experimental difficulties in this energy range reliable neutron polarization measurements are very scarce.

Numerous measurements of elastic scattering from carbon exist in the neutron energy range below 8.5 MeV. At higher energies a measurement at 24 MeV of the angular distribution of the elastic polarization has been made [1], and at 14.7 MeV measurements of asymmetry [2] and polarization [3] have been published, where however elastic and inelastic scattering were not separated.

Therefore in the present experiment the neutron polarization has been measured at $E_n = 15.85$ MeV for $^{12}C(n,n)^{12}C$ and $^{12}C(n,n')^{12}C$ ($Q = -4.43$ MeV). The measurements, briefly reported in [4], have been made by determining the scattering asymmetry of polarized incident neutrons. The d-t reaction was used. The deuterons of a VAN DE GRAAFF accelerator struck a Ti-^{3}H target which had an effective thickness of 280 keV, the mean deuteron energy within the target was 1.90 MeV. The neutrons, emitted at $\Theta_{lab} = 70.0^\circ$ relative to the direction of the deuteron beam, had a mean energy of 15.85 MeV. At a distance of 100 cm they hit the carbon scatterer. This was a cylindrical plastic scintillator NE 102 A with a diameter of 3.82 cm and a height of 10.16 cm, with its axis perpendicular to the scattering plane. The neutrons scattered from carbon nuclei in the scintillator at angles $\pm\Theta$ were simultaneously detected by two scintillation counters A and B at the end of two time-of-flight paths with a length of 300 cm each.

In order to avoid instrumental asymmetries the scattering angles to the left and to the right were made equal very carefully. During the measurements the position of the focus on the target could be controlled remotely and corrected at any time with an accuracy of ± 0.3 mm. The whole uncertainty of the mean scattering angles to the left and to the right was ± 2 minutes.

The scintillations produced by carbon nuclei are very faint. Within the range of scattering angles $\Theta_{lab} = 30^\circ$ to 80° the recoil energies lie between 0.33 and 2 MeV. The scintillation efficiency is about 1.6% relative to electrons of the same energy [5, 6]. Therefore the scintillation pulses of the carbon nuclei are equivalent to electron pulses of 5.3 to 32 keV. If time-of-flight measurements are to be made with pulses of this height it is necessary to suppress multiplier noise in order to reduce the background caused by chance coincidences. This was done by mounting one multiplier 56 AVP on each end of the scattering scintillator. The pulses of the anodes were fed into a fast coincidence circuit. The output pulses of it mainly come from scintillations while statistical independent noise pulses of the two multipliers cause chance coincidences only.

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