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THE RELATION BETWEEN THE TEMPERATURE DEPENDENCE OF ELECTRICAL RESISTANCE AT LOW TEMPERATURES AND THE GALVANOMAGNETIC EFFECT IN STRONG MAGNETIC FIELDS

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The electrical resistance of nickel-copper alloys with 39.6, 44.55 and 49.6% Cu has been studied between 7 and 30° K. By applying the $T^{3/2}$ law for the temperature dependence of spontaneous magnetization, I_s, the specific resistivity, ρ, can be related to the ferromagnon concentration $n = 1 - I_s/I_0$ (I_0 is the magnetization at $T \to 0$) and the numerical value of the coefficients $(\rho - \rho_0)/n$ derived, where ρ_0 is the residual resistivity. A comparison between this coefficient and the value of $\Delta\rho/\Delta n$ ($\Delta\rho$ and Δn are the changes in ρ and n caused by changes of true magnetization in strong magnetic fields) shows them to be of the same order of magnitude, within the limits of experimental error. This is taken as indirect evidence for the validity of the assumption that the electrical resistance of ferromagnetic alloys at low temperatures is connected with the inhomogeneities in magnetization of the lattice.

WE have previously[1] studied the electrical resistance of nickel, iron, and nickel-copper alloys (up to 25% Cu) in the temperature range from 2 to 78° K, and showed that the temperature variation of resistivity up to about 30° K is well described by the approximate formula

$$\rho = \rho_0 + C\frac{I_0 - I_s}{I_0} = \rho_0 + Cn,$$

where C is a constant and n is the ferromagnon concentration. The existence of a connection between the variation in ρ and the spontaneous magnetization I_s is taken to be a consequence of the scattering of conduction electrons by spin waves. The extra resistance due to this process is described theoretically[4] by formulae containing terms aT^3,[2] bT^2,[3] and $\alpha T + \beta T^2$. As the theory does not give the magnitude of the additional resistance it is not possible to make a quantitative comparison between theory and experiment.

Nevertheless, the present authors, together with Kondorskiĭ, presented indirect evidence of a connection between the temperature dependence of electrical resistivity at low temperatures and inhomogeneities of magnetization in ferromagnetic metals. The change in resistance of iron and nickel between 8 and 30° K was compared with the change of resistance in high magnetic field, i.e., with the magnitude of the galvanomagnetic effect $\rho^{-1}\Delta\rho/\Delta H$, which is proportional to the increase or decrease in true magnetization and is thus related to the increase or decrease in "ferromagnon" concentration. In the previous work[1] the values of the change in $\rho^{-1}\Delta\rho/\Delta H$ and of the *susceptibility*, $\Delta I_s/\Delta H$, for nickel and iron were determined from data referring to room temperature and were taken from the work of other authors.

The aim of the present work was to obtain reliable experimental data to confirm the relation between the temperature dependence of resistivity

TABLE I. Specimens — Ni-Cu alloys

Cu concentration %	$\frac{\Delta I_s}{\Delta H}\cdot 10^4$, G/Oe	$\rho_T\cdot 10^6$, Ω·cm	$\frac{1}{\rho_T}\frac{\Delta\rho}{\Delta H}\cdot 10^6$, Oe^{-1}	I_0, G	Θ′, °K
39.6	0.54*	34.39	0.26	163	325
44.55	1.0	39.34	0.33	120	210
49.6	2.9	44.48	0.5	87	185

*The susceptibility of the 39.6% Cu alloy was taken from the measurements of Rode and Chang Shou-Kung on the same specimen.

and the galvanomagnetic effect at high fields.

We used nickel-copper alloys with larger copper content: 39.6, 44.55, and 49.6% Cu. These alloys were chosen because of their low Curie temperatures, which makes the low temperature values of $\Delta\rho/\Delta H$ and $\Delta I_S/\Delta H$ larger than in the pure metals (Fe or Ni) and accurately measurable. For the resistivity measurements, specimens were made in the form of wires with diameter d = 0.2 mm and length l = 150 mm, and for the measurement of paraprocess susceptibility they were ellipsoids of revolution with axes 5 and 50 mm. The specimens were annealed in vacuum at 900° C for six hours and then slowly cooled at the rate of 50° per hour. The method of measuring the resistivity was described previously.[1] The paraprocess susceptibility was measured in a field of 5000 oe at 20.4 and 14° K by a ballistic method.

EXPERIMENTAL RESULTS

The electrical resistance of the alloys was measured between 2.2 and 30° K at intervals of 1 – 2°. Table I shows the values of $\Delta I_S/\Delta H$ and of ρ_T at 20.4° K.

Figure 1 shows the dependence of the relative change of electrical resistance, $\Delta\rho/\rho_T$ on the field intensity for the different alloys, at 20.4° K. The values of $\Delta\rho/\rho_T\Delta H$ in the high field region (the linear part of the curves in Fig. 1) are given in the fourth column of Table I. The fifth and sixth columns give the values of I_0 and Θ′ obtained on the same specimens by Kondorskiĭ et al.[5] I_0 is the magnetization at T = 0° K and Θ′ is the parameter in the three-halves law

$$I_s = I_0[1-(T/\Theta')^{3/2}].$$

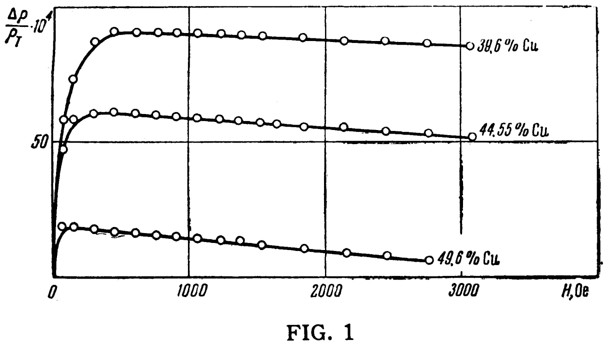

FIG. 1

The dependence of $\rho-\rho_0$ on $(T/\Theta')^{3/2}$ is plotted in Fig. 2 (ρ_0 is the residual resistance). It can be seen that ρ is linearly related to $(T/\Theta')^{3/2}$ = n, and consequently to $(I_0-I_S)/I_0$, i.e., to the ferromagnon concentration. The calculated values of $(\rho-\rho_0)/n$ are shown in Table II.

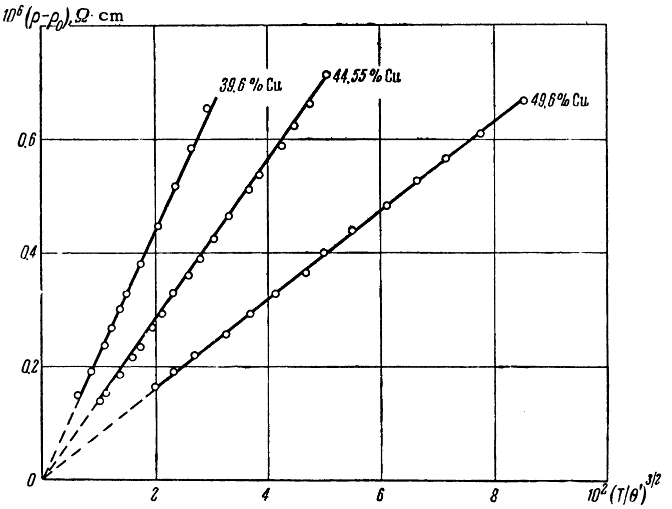

FIG. 2

TABLE II

Cu concentration %	$\frac{(\rho-\rho_0)}{n}\cdot 10^6$	$(\Delta\rho/\Delta n)\cdot 10^6$	
		20,4° K	14° K
39.6	22	27	25
44.55	14	15.6	15.1
49.6	7.9	6.7	7.2

The values of $(\rho-\rho_0)/n$ are compared with $\Delta\rho/\Delta n$, where $\Delta n = \Delta I_S/I_0$ and $\Delta\rho$ is the change in resistivity connected with the change in true magnetization in high magnetic fields. The values of $\Delta\rho/\Delta n$ were derived from the formula

$$\frac{\Delta\rho}{\Delta n} = \left(\frac{1}{\rho_T}\frac{\Delta\rho}{\Delta H}\right)\frac{\rho_T I_0}{(\Delta I_s/\Delta H)}\,.$$

Values of $\Delta\rho/\Delta n$ calculated from the data of Table I are shown in Table II. Comparison of $(\rho-\rho_0)/n$ and $\Delta\rho/\Delta n$ shows that they agree within the limits of experimental error .

We calculated $\Delta\rho/\Delta n$ for all the alloys at 14° K as well. The values obtained are in the fourth column of Table II. Comparison of the third and fourth columns indicates that $\Delta\rho/\Delta n$ remains constant within the experimental errors.

There is thus a definite connection between the temperature dependence of electrical resistance at low temperatures and the galvanomagnetic effect in high fields. This connection can be explained if it is assumed that in both cases the change in electrical resistance is produced by the scattering of conduction electrons by the inhomogeneities of magnetization.

In conclusion the authors would like to express their gratitude to Professor E. I. Kondorskiĭ for valuable suggestions made during discussion of the results of this work.

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