ANOMALOUS ELECTRICAL RESISTIVITY AND THE EXISTENCE OF GIANT MAGNETIC MOMENTS IN Ni-Cu ALLOYS*

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The electrical resistivity of Ni-Cu alloys near the critical composition for ferromagnetism is found to remain anomalous up to temperatures of about 600°K. This behavior is attributed to the existence of giant magnetic polarization clouds and to their ultimate disappearance at these temperatures.

Recent neutron scattering experiments[1] on weakly ferromagnetic Ni-Cu alloys have shown that the magnetization in these alloys is distributed inhomogeneously in polarization clouds of large total moment extending over many atoms. Susceptibility measurements[2] have subsequently demonstrated that these giant magnetic polarization clouds persist as superparamagnetic moments well into the paramagnetic composition range (<44 at.% Ni). In this Letter, electrical resistivity data for Ni-Cu alloys are presented which indicate that these giant polarization clouds cause anomalous electron scattering from low temperatures up to about 600°K and that they probably cease to exist at this same high temperature, essentially independent of alloy composition.

The resistivity of six Ni-Cu alloys ranging in composition between 30 and 50 at.% Ni was measured between 1.5 and 700°K using standard dc four-terminal techniques. The data are shown in Fig. 1. It should be noted that the ordinate scale is broken and that the relative variation in resistivity for each curve over the entire temperature range is less than 6%.

For the ferromagnetic alloys, there is a sudden decrease in resistivity below the Curie temperature T_C (identified in the figure). In all other respects, the alloys behave in the same characteristic manner. The minimum which appears at low temperatures has been reported elsewhere,[3-5] and the temperature of this minimum varies with alloy composition, as shown in Fig. 1. A maximum follows at higher temperatures, and the temperature at which it occurs also varies with Ni content. Then a minimum and/or a rapid increase in slope suddenly

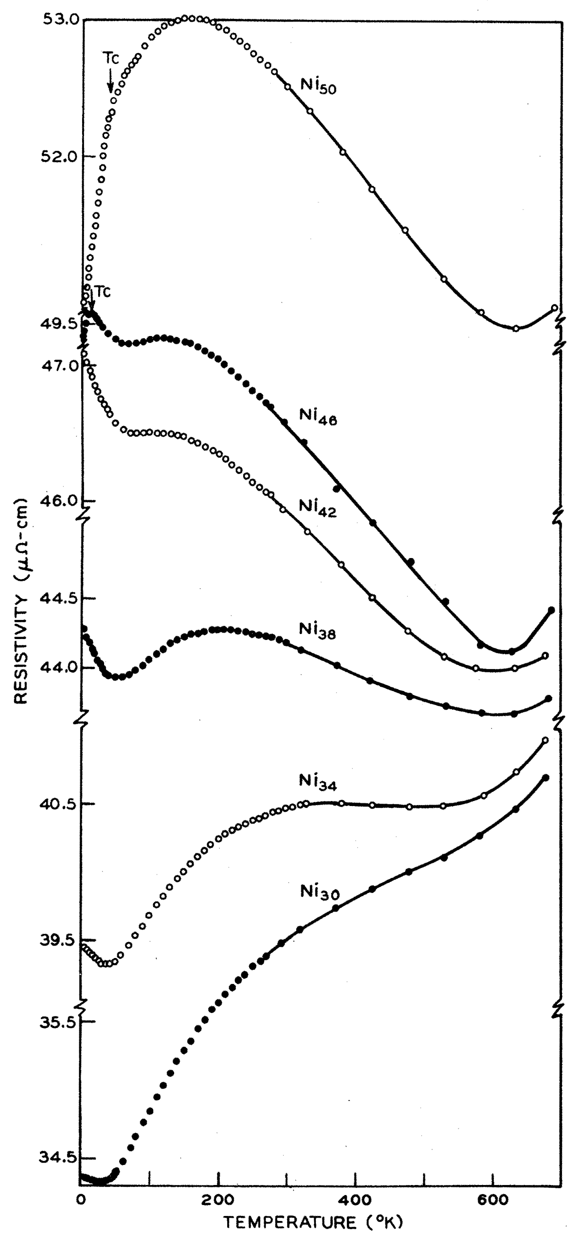

FIG. 1. The electrical resistivity of Ni-Cu alloys as a function of temperature.

occurs for each alloy at about 600°K, above which (according to earlier measurements up to 1270°K by Schüle and Kehrer[6]) the resistivity continues to rise monotonically.

The change in resistivity in the 200-600°K region could be interpreted as a sum of two contributions: an increasing term due to phonon scattering, and a decreasing term due to spin-disorder scattering from the local moment clouds. Since the latter can be expected to vary as some simple direct function of the moment, it seems reasonable to interpret the data as indicating that the effective paramagnetic moment of each cloud is smoothly decreasing to zero as the temperature rises to 600°K. Whether the structure in the data below 50°K for the paramagnetic alloys represents an additional effect, such as Kondo scattering, or an anomalous change of the moment per cloud, cannot be determined at this time. The low-temperature behavior of the ferromagnetic alloys can clearly be interpreted as the freezing out of spin-disorder scattering.

The fact that the spin-disorder scattering disappears at about 600°K, independent of alloy composition, indicates that the giant polarization clouds persist up to a temperature near the Curie point of nickel (approximately 625°K). This suggests that within a statistical Ni-rich local region which is the nucleating site of a magnetic polarization cloud in Ni-Cu,[2] the exchange forces are quite comparable in strength with those in pure nickel.

A detailed interpretation of the resistivity below 600°K has not been possible to date. Additional measurements on Ni-Cu alloys with lower Ni content will be made in an effort to extract the magnetic-scattering contribution to the resistivity.

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KONDO SIDEBANDS

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Logarithmic resonances away from the Fermi level are obtained when the magnetic ion of the *s-d* model is subject to a crystal field. Indications exist that such resonances are observed in the resistivity-versus-temperature curve of $CeAl_3$.

Recently a number of experimental results have been published[1-3] concerning the behavior as a function of temperature of the resistivity of several intermetallic compounds containing cerium. Some puzzling aspects of these measurements have stimulated the effort whose results are to be reported presently.

A variation of the *s-d* model has been considered. The system consists of a gas of charge carriers and of a periodic array of spins [these "localized" spins (S) in reality are the total angular momenta (J) of the Ce atoms]. The assumption is made that there exists no correlation between the motion of any two spins. This assumption is valid in the paramagnetic region of the system, when the molecular-field approximation is adopted. Under these conditions each localized spin scatters the charge carriers independently and the fact that a periodic array of spins exists is irrelevant in what follows. Periodicity plays, on the contrary, an important role if these considerations are extended to the ordered phase of the system.[4] This extension is not included in the present Letter.

Each localized spin has $S=\frac{5}{2}$ (the calculation is to be applied to Ce ions); the six energy levels E_m ($m=1, 2, \cdots, 6$) of the spin are split by a hexagonal crystal field into three doublets (this assumption applies to $CeAl_3$). The doublet states are eigenstates of the spin components S_z if the crystal-field z axis is chosen as the axis of quantization. As acceptable sequence of levels is the following: The $\pm\frac{5}{2}$ doublet lies lowest; above it, at an energy distance ΔE, the $\pm\frac{3}{2}$ doublet is to be found, while the