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THE EFFECT OF 4d AND 5d TRANSITION METAL IMPURITIES ON THE RESIDUAL RESISTIVITY OF Au, Cu, Zn AND Al

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Abstract.- The residual resistivities of Au, Cu, Zn and Al-based 4d and 5d transition metal alloys have been measured between 1.5 and 4.2 K. The obtained results are compared with those of 3d and with the theoretical conclusion of Friedel.

Although the electron configurations of the 4d and 5d transition metals are similar to those of 3d elements, their physical properties are very different. Among the 3d transition metals, Fe, Co and Ni are ferromagnetic, and Cr and Mn are antiferromagnetic, while the 4d and 5d metals are never in such magnetically ordered states. In this respect, it will be an interesting problem to compare physical properties of isolated atoms dissolved in simple metals with those of 3d atoms in similar states. To obtain systematic results, it was attempted to measure the residual resistivities of all such alloys based on Au, Cu, Zn and Al.

The materials used for the preparation of alloys were 99.999% Au, 99.998% Cu, 99.9999% Zn, 99.998% Al and 99.9 or 99.99% 4d and 5d transition metals.

Au, Cu and Zn-based alloys were melted in a quartz tube. For the case of Au and Cu-based alloys, they were melted in high vacuum (<10^{-5} torr) for two hours at 1150°C and were kept at 1000°C for one hour. For the case of Zn-based alloys, they were melted under 110 torr pure Ar for three hours at 600°C. Subsequently all those alloys were rapidly quenched in ice water. Al-based alloys were prepared by arc melting method. After cold rolling to a thickness of 0.05 mm, they were cut into strips 2 mm wide and 40 mm long. They were finally annealed in order to remove strain. The electrical resistivities were measured with the conventional four terminals method between 1.5 and 4.2 K. Estimated errors in the absolute values of the electrical resistivities were ± 15%.

The main experimental difficulty lies in the fact that the solubilities are very limited in Au, Cu, Zn and Al. The concentrations were determined by weighing because of the difficulty of quantitative analysis. The method of sample preparation was carefully examined for the melting time, the solubility limit, the homogeneity of the solid solution, the possible influence of precipitation effects during the heat treatment for removing strain and the influence of size effect.

For all the dilute alloys investigated, there is no temperature dependence of the residual resistivities over the range 1.5-4.2 K. This fact shows that 4d and 5d elements in Au, Cu, Zn and Al are nonmagnetic in this range. The concentration dependence is linear. In figure 1, the values obtained for the residual resistivities of Au, Cu, Zn and Al-based 4d and 5d dilute alloys per atomic percent Δρ/C are shown as functions of the impurity atomic number /2,5/. For comparison, the 3d cases are drawn in the same figure (broken curve).

The 3d cases have well been investigated both experimentally and theoretically, and are well interpreted by the concept of d resonance introduced by Friedel /7/. Our systematic studies on the series of 4d and 5d elements in Au, Cu and Zn revealed the situation different from that for the 3d elements. The residual resistivities of 4d and 5d alloys agree with each other and are invariably smaller than those of 3d /2,5/. These experimental results cannot be explained by the Friedel's formula. On the other hand, those of Al-based 4d alloys agree with those of 3d, and those of 5d dilute alloys are smaller than those of 3d. In this case, the experimental results are explained by incorporating the spin-orbit coupling on the impurity atom into the Friedel's resonance model /6/. But the resistivities of the Au, Cu and Zn based alloys can-
not be explained in that way.

For one thing, since the spin-orbit coupling constant of a 5d electron is about three times as large as that of 4d, we cannot understand the reason why the 4d and 5d atoms behave similarly in the resistivity curve. Furthermore, it is almost impossible to account for such an extraordinary departure from the Friedel's formula. It is difficult to think of a mechanism which operates almost equally in 4d and 5d elements and entirely differently in 3d elements. Unified explanations of these experimental results are not considered at present, but are left to future theoretical investigations. Studies of anisotropy of electron-impurity scattering by dHvA effect and screening charge distribution measurements by NMR are desirable for future experimental investigations.

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