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EFFECT OF PRESSURE ON THE KONDO TEMPERATURES OF Au(Fe) AND Au(Mn)

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The electrical resistivity of four Kondo systems, Au–(5 p.p.m. Fe), Au–(39 p.p.m. Fe), Au–(17 p.p.m. Mn) and Au–(50 p.p.m. Mn) has been measured in the temperature range 1.3–20 K at pressures up to 80 kbar. The Kondo temperature T_K is found to increase initially with pressure at the rate of 1.1%/kbar for Au(Fe) and 6%/kbar for Au(Mn). The volume dependence of the effective exchange constant J_{eff} is derived.

THE HIGH PRESSURE technique has distinct advantages compared with alloying when it is essential to vary the electronic and magnetic properties of a solid in a well defined manner. In recent measurements[1,2] of the electrical resistivity of the classic Kondo alloy Cu–(110 p.p.m. Fe) from 1.3–40 K, it is found that application of pressures as high as 82 kbar causes the Kondo temperature $T_K (T_K = T_f \exp(1/n(E_f)J_{eff})$, where T_f is the Fermi temperature, $n(E_f)$ is the density of states at the Fermi surface and J_{eff} is the effective exchange constant) to increase initially at the rate of + 1.1%/kbar without a detectable change in the spin S or the potential scattering at the magnetic impurity site. The existence of a "universal" resistivity law $\rho = \rho(T/T_K)$ for Cu(Fe) was also confirmed. It would be of interest to investigate to what extent the above results for Cu(Fe) can be generalized to other very dilute magnetic alloys with different combinations of magnetic impurity and host metal. Of special importance would be alloys possessing appreciably different Kondo temperatures from Cu(Fe), thus allowing in the temperature range 1.3–20 K a study of the effect of pressure on an entirely different section of the "universal" resistivity curve. The aim of such studies is not only to check the various theoretical descriptions of such dilute spin systems but also to contribute to the understanding of the more general question of the nature of the interaction of an isolated magnetic impurity with its surroundings.

In this paper we present high pressure resistivity measurements on four further Kondo alloys [Au–(5 p.p.m. Fe), Au–(39 p.p.m. Fe), Au–(17 p.p.m. Mn) and Au–(50 p.p.m. Mn) where the nominal impurity concentrations are given]. Comparison of our measurements with the results of Ford[3] and Loram[4,5] would imply concentrations of 7 p.p.m. Fe, 32 p.p.m. Fe, 34 p.p.m. Mn and 68 p.p.m. Mn, respectively. The Kondo temperatures of these alloys for zero pressure lie far below that of Cu(Fe) [Au(Fe), $T_{K0} \approx 0.24$ K;[3] Au(Mn), $T_{K0} \approx 10^{-4}$ K;[6] Cu(Fe), $T_{K0} \approx 24$ K].[5] The concentrations of the above alloys have been chosen so low that interimpurity interaction effects are unimportant in our temperature range. The low temperature resistivity of the Au used in preparing the alloys (99.9999% pure from Cominco Gardner) showed a slight increase after being treated in the same way as the above dilute alloys, indicating a magnetic impurity concentration less than 0.8 p.p.m. Fe. This effect is negligible in Au(Fe) alloys but must be taken into consideration in Au(Mn) due to the fact that Fe

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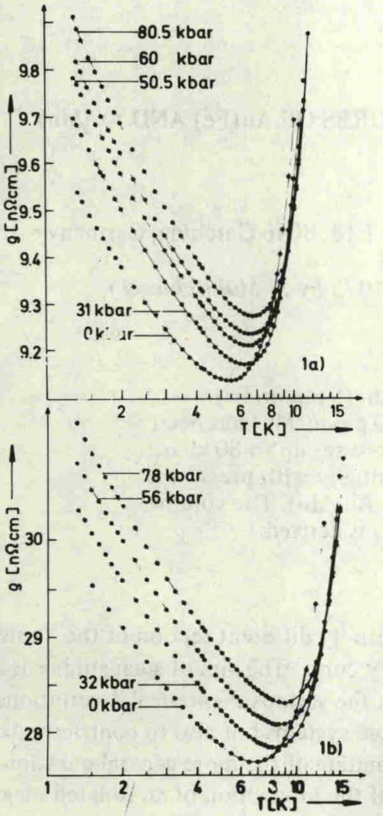

FIG. 1. Measured resistivity vs temperature. Left is spin-scattering resistivity, right is phonon resistivity. The solid lines connecting dots are to distinguish data at different pressures. (a) Au–(5 p.p.m. Fe), (b) Au–(39 p.p.m. Fe).

shows a 12 times stronger increase of the Kondo resistivity in the temperature range reported. The sample preparation and high pressure techniques have been discussed in detail in a previous publication.[2]

The results of our resistivity measurements at high pressures on the Au(Fe) alloys are shown in Fig. 1. At a given pressure the competition between the spin-scattering resistivity from the magnetic impurity and the phonon-scattering resistivity from the Au-lattice gives rise to a resistivity minimum at T_{min}. Application of pressure is seen for both alloys to shift the spin-scattering curve to higher temperatures and to increase T_{min}, the step height $\rho(T = 1.5\ K) - \rho(T_{min})$, and the slope $|d\rho_{spin}/d \log T|$.

In these measurements it was not possible to

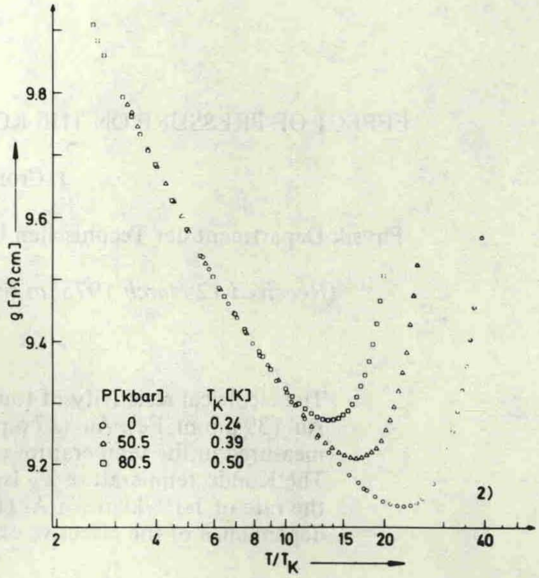

FIG. 2. Resistivity of Au–(5 p.p.m. Fe) vs reduced temperature T/T_K for several pressures.

check for the existence of a "universal" resistivity law $\rho = \rho(T/T_K)$ as was done for Cu(Fe). Rather, it was necessary to *assume* the existence of this law and the pressure independence of S and the potential scattering in order to be able to determine the shifts of T_K with pressure. The relative vertical position of the curves in Fig. 1 to each other was determined by requiring that all spin-scattering curves overlap accurately when shifted in temperature on a log T plot.[7] Using this procedure one derives a relative initial increase of T_K with pressure of $\delta = (\Delta T_K/T_{K0})/\Delta p \approx +1.1\%/\text{kbar}$ for the Au(Fe) alloys. In Fig. 2 plots of the resistivity of Au–(5 p.p.m. Fe) are shown as a function of the reduced temperature T/T_K and are seen to overlap within the experimental accuracy over the entire range $T < T_{min}$. For $T \geqslant T_{min}$, the phonon-scattering and deviations from Matthiessen's rule become large and prevent any possibility of overlap. The determination of δ using the above procedure is accurate to roughly ± 20%.

An independent method of estimating the change of T_K consists in measuring the pressure dependence of the slope of the spin-resistivity curve. Since for $T \gg T_K$, $|d\rho_{spin}/d \log T| \propto |J^3_{eff}|$,[8] the observed increase in slope seen in Fig. 1 with pressure implies