THE SPIN-GLASS TRANSITION AND ANOMALOUS HALL EFFECT IN CONCENTRATED AuFe, AuMn & AuCo.

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Résumé.- L'influence du champ magnétique sur la résistivité Hall (ρ_H) et sur la résistance magnétique des alliages polycrystallins Au + 11,0 % at. Fe, Au + 11,6 % at. Mn et Au + 11,0 % at. Co a été mesuré à 4,5 K. Tous les trois montrent un grand effet Hall anormal dû à l'interaction spin-orbitale. L'influence de la température sur le ρ_H à champ faible montre un maximum à la température de transition du verre de spin.

Abstract.- The field dependence of the Hall resistivity (ρ_H) and magnetoresistance has been measured at 4.5 K for polycrystalline Au + 11.0 at. % Fe, Au + 11.6 at. % Mn and Au + 11.0 at. % Co. All three alloys show a large anomalous Hall effect due to spin-orbit coupling. The temperature dependence of the low-field ρ_H shows a peak at the spin-glass transition temperature.

The Hall effect in a number of noble metal-transition metal alloys displays an anomalous component /1,2/ that has been attributed to the skew or asymmetric scattering of electrons by the magnetic impurities /2-4/. The skew scattering arises from spin-orbit coupling which makes scattering events asymmetric with respect to the plane containing the magnetic moment and the incident electron's velocity. This asymmetry is present in the absence of an external field. When an external field is applied to a sample in the normal Hall geometry there is a net alignment of the moments and the asymmetric scattering events combine to produce an extra term in the Hall resistivity ρ_H. This skew term follows the magnetization closely, eventually saturating, while the Lorentz contribution to ρ_H increases with field. The sign of the skew scattering contribution to ρ_H depends on the position of the Fermi level with respect to the split virtual bound states, and the phase shifts involved in the scattering /4/. Detailed calculations of such phase shifts when the magnetic moments are not necessarily isolated have not yet been done.

In fig. 1 the variation of ρ_H and the magnetoresistance $\Delta\rho/\rho_{B=0}$ is shown for 3 different alloys at 4.5 K. These alloys have approximately the same composition (∿11 at. % solute) and are spin-glasses in the sense that they show characteristic peaks in the low field a.c. susceptibility /5/. In all three samples the magnetoresistivity is negative due to the freezing out of spin-flip scattering as the applied field is increased. For the Fe and Mn alloys ρ_H is negative, as is the skew contribution. However, for the Co alloy ρ_H is initially positive and changes sign with field as the Lorentz contribution becomes dominant.

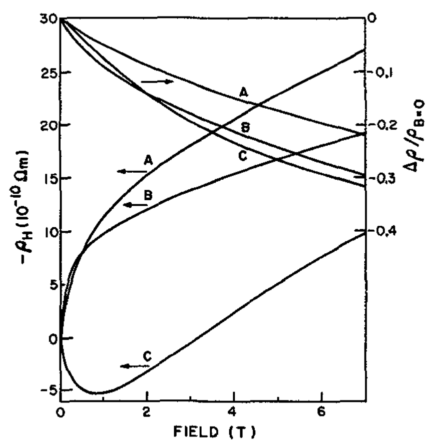

Fig. 1 : Field dependence of the Hall resistivity ρ_H and magnetoresistance $\Delta\rho/\rho_{B=0}$ at 4.5 K for A : Au + 11.0 at.% Fe, B : Au + 11.6 at.% Mn, C : Au + 11.0 at.% Co.

The positive sign of ρ_H in the AuCo alloy at low fields reflects the fact that the Lorentz term is comparatively small at these fields and the observed ρ_H arises mainly from the skew contribution from the Co impurities. (Co itself shows a positive Hall coefficient /6/.) By inverting the magnetoresistivity tensor one obtains the magnetoconductivity tensor and in particular $\sigma_{21}(=\sigma_H)$. This element contains a term (σ_{21}^L) linear in field ($\omega\tau << 1$) plus the skew contribution ($\Delta\sigma_{21}$) i.e.

$$\sigma_{21} = \sigma_{21}^L + \Delta\sigma_{21}.$$

Extraction of the linear term enables one to determine $\Delta\sigma_{21}$ and the saturation value for this contribution. For the 3 alloys studied $\Delta\sigma_{21}$ (sat.) is 2.7 ± 0.1 (Fe) 16 ± 1 (Mn) and -12.5 ± 0.5 (Co), all units being $10^3\ \Omega^{-1}\mathrm{m}^{-1}$.

In all 3 alloys at low fields the contribution of the Lorentz term to ρ_H is overwhelmed by the skew term. This latter term is dependent on the magnetization of the alloy and thus the very low field ρ_H is a monitor of the magnetic state of the alloy. With this in mind low field measurements of ρ_H have been made on the alloys as a function of temperature to look for the appearance of the spin-glass state. (Because of the concentration of the alloys studied some authors would prefer to call them "cluster glasses" or " mictomagnets".) Fig. 2 shows ρ_H (T) for the alloys, at low fields. Note that for the AuCo alloy ρ_H (T) is positive over the whole temperature range, but for the other two alloys it is negative. In all cases $|\rho_H|$ increases as the temperature is raised from 4.2 K and after passing through a maximum, decreases again. The decrease at the higher temperatures represents the disordering influence of temperature on the magnetization of the system in a normal Curie-Weiss sense. The increase of $|\rho_H|$ with T at the lowest temperatures reflects the increase in alignment of moments in the external field, as kT increases in comparison with the local spin-glass ordering fields.

The peak in $|\rho_H(T)|$ is pronounced in both the AuCo and AuFe alloys but considerably broadened in the AuMn sample. It is a general feature of the $\rho_H(T)$ measurements that as the applied field is increased so the appearance of a maximum or peak is smeared out, because the spin-glass state is progressively disrupted by the larger applied fields /3/. Thus a smaller applied field could well produce results for the AuMn sample comparable with those for the other two samples. The maxima in the $|\rho_H(T)|$ measurements suggest freezing temperatures of 35 K (AuFe) 34 K (AuMn) and 19 K (AuCo) compared with susceptibility cusps at about 34 K, 33 K and 20 K, respectively /5/.

Studies of AuCo alloys have indicated that the Kondo temperature for isolated Co atoms is ∿200 K and about an order of magnitude lower for pairs of Co atoms /7/.

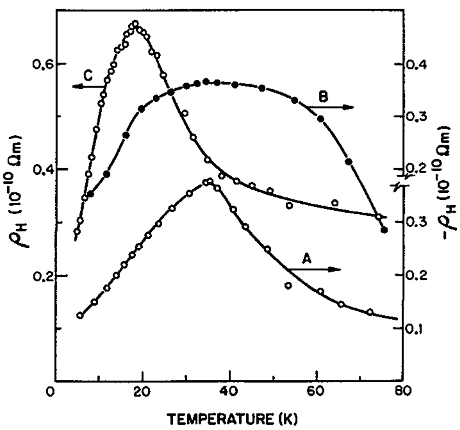

Fig. 2 : Temperature dependence of ρ_H for A : Au + 11.0 at.% Fe at 60 G, B : Au + 11.6 at.% Mn at 60 G, C : Au + 11.0 at.% Co at 200 G. Note that ρ_H for alloy C is positive.

Only groups of 3 or more Co atoms are magnetic at cryogenic temperatures. The behaviour of ρ_H in the AuCo alloy is thus dominated by groups or clusters of Co atoms. Since the results from the other alloys are very similar it is clear that magnetically coupled clusters must be very important in determining the behaviour. This could be deduced from a purely statistical basis since in an 11% fcc alloy no more than 25 % of the solute atoms are isolated (no NN). The slight shoulder observed below T_o in $|\rho_{21}(T)|$ may be connected with the fact that differently sized clusters can be expected to behave differently, since $|\rho_{21}(T)|$ reflects not only the degree of alignment of moments but also the degree of asymmetry in scattering from the different scatterers.

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