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SPIN GLASS ORDERING IN  $(Cr_{98}Mo_2)_{90}Fe_{10}$

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Résumé.- Nous présentons les premières mesures qui montrent que, dans une matrice contenant des ondes de densité de spin (S.D.W.), le fer à fortes concentrations (10 at %) a le comportement caractéristique d'un verre de spin. L'onde de densité de spin peut par conséquent co-exister avec d'importants agglomérats de fer.

Abstract.- We present the first measurements to show that Fe in a spin density wave (S.D.W.) host shows characteristic spin glass behaviour at high concentrations (10 at %). The S.D.W. therefore co-exists with large Fe clusters.

Chromium and dilute CrFe are well known to support itinerant spin density wave (S.D.W.) antiferromagnetism/1/. Below the Néel temperature,  $T_N$ , Fe impurities appear to be weakly coupled and the impurity susceptibility obeys a Curie law /2/. More concentrated alloys are superparamagnetic and ferromagnetic /3/. Both the antiferromagnetic Néel temperature and the ferromagnetic Curie temperature extrapolate to zero close to 20 at % Fe /2/. This suggests that the two magnetic regimes are exclusive.

We here report measurements on  $(Cr_{98}Mo_2)_{90}Fe_{10}$  which show the system to be a spin glass.

The CrMo host is a S.D.W. system in which  $T_N$  can be varied /4/. Cr and Mo are isoelectronic ; the addition of Mo reduces  $T_N$  by 13.6 K per at % Mo /5/.

The alloy was prepared from 5N purity starting materials by arc melting. The sample was spark cut and annealed at 1000°C for five days, quenched to 77 K and kept at 77 K prior to use. Resistance measurements were made using a four terminal A.C. technique. The results are shown in figure 1. The resistivity shows the same qualitative behaviour as that of pure Cr with 11.2 at % Fe /6/. The minimum at 61 K agrees well with the temperatures of minima observed in  $(Cr_{98}Mo_2)$  samples with lower concentrations of Fe./7/. It should therefore be associated with the onset of S.D.W. formation.

Magnetization measurements were made using a vibrating sample magnetometer sensitive to a magnetization of  $10^{-5}$  emu in an applied field of 100 Oe. The impurity susceptibility,  $\Delta\chi = \chi - \chi(\text{host})$ , was obtained in the following ways. The closed circles (●) were obtained by cooling the sample in zero field from room temperature to 1.1 K and tracing the magnetization against applied field (M vs H)

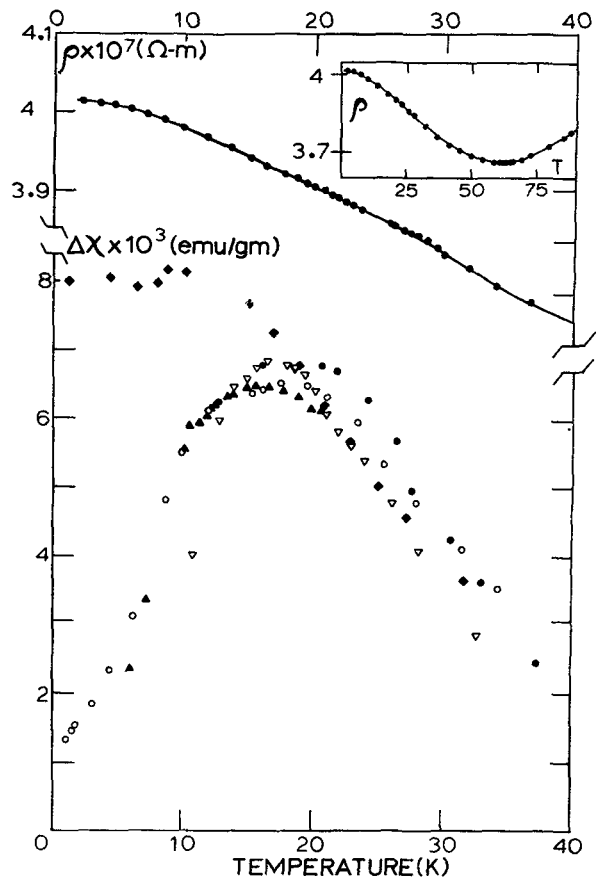


Fig. 1 : The resistivity and susceptibility of  $(Cr_{98}Mo_2)_{90}Fe_{10}$  as a function of temperature. The circles (●,○) represent the slopes of M vs H curves, measured between  $\pm 100$  Oe and  $\pm 10$  Oe respectively. The triangles (▽,▲) were taken from the induced magnetization measured at fixed fields of 10 Oe and 0.8 Oe. The diamonds (◆) show the magnetization of the sample, field cooled in 500 Oe.

between  $\pm 100$  Oe at successively higher temperatures. Below 12 K, these curves showed increasing re-

manence down to 4.2 K. This decreased to less than 10 % of the 4.2 K value at 1.1 K.  $\Delta\chi$  is only plotted above 12 K where no remanence was observed.

The open circles (o) were obtained in the same way but at fields between  $\pm 10$  Oe. The time taken for each measurement was less than 10 seconds and the traces were linear and repeatable. Therefore, these points approximate to the reversible susceptibility,  $\chi_{rev}$ , measured by an A.C. technique. As can be seen, both sets of measurements define a maximum in the impurity susceptibility. Within the accuracy of the measurements, the position of the peak moves to a lower temperature for the points measured in smaller applied field sweeps.

The triangles ( $\blacktriangle, \nabla$ ) were obtained by cooling the sample from above 30 K to 4.2 K, then applying a fixed field at successively higher temperatures, and measuring the induced magnetization. The open triangles correspond to an applied field of 10 Oe and the closed to 0.8 Oe. While the magnitude of the susceptibility (induced magnetization  $\div$  applied field) is slightly smaller than that obtained from the slope of the M vs H traces, the position of the peak susceptibility for both sets of data obtained in 10 Oe ( $\nabla$ ) is roughly the same. Moreover, the data again suggests that the peak moves to lower temperatures when a smaller applied field is used.

The remaining points ( $\blacklozenge$ ) were obtained by cooling the sample from above 30 K in a fixed applied field of 500 Oe. The total magnetization measured in this way is seen to saturate below 12 K. This clear difference between the equilibrium magnetization (field cooled) and the non-equilibrium behaviour (cooled in zero field) below 18 K is characteristic of spin glass behaviour<sup>8/</sup>.

We also note that while the temperature dependence of the resistivity of  $(Cr_{98}Mo_2)_{90}Fe_{10}$  is qualitatively the same as that of  $Cr_{89}Fe_{11}$ , it is not similar to that observed at lower Fe concentrations in either pure Cr<sup>6/</sup> or  $Cr_{98}Mo_2$ <sup>7/</sup>.

We conclude that the behaviour of Fe in a S.D.W. host changes near 10 at % of impurity to one in which the S.D.W. state co-exists with large Fe clusters. The S.D.W. formation gives rise to a minimum in the resistance while the clusters dominate the magnetic properties at low temperatures. We suggest that neutron diffraction measurements should be made to clarify this behaviour.

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