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NUCLEAR ORIENTATION EXPERIMENTS ON DILUTE ALLOY OF Pt Mn

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Résumé.— Des expériences d'orientation nucléaire faites sur des alliages dilués de Pt Mn montrent à faible concentration ($x \leq 40$ ppm) le couplage entre impuretés au-dessus de leur température d'ordre, à concentration intermédiaire l'existence d'un régime verre de spin, et à plus haute concentration la présence d'un ordre de type antiferromagnétique.

Abstract.— Nuclear orientation measurements were performed on dilute alloys of Pt Mn. At low concentration $x \leq 40$ ppm, coupling between impurities is observed above their ordering temperatures, at intermediate concentration $x \approx 1\%$ a spin glass coupling is detected whereas for the higher concentration $x = 2.5\%$ an antiferromagnetic-like ordered regime appears.

In the spin glass regime recent nuclear orientation (N.O.) experiments with $^{54}$Mn probe have been performed on Ag Mn, Au Mn, Au Cr, Au Fe alloys /1/ /2/ /3/. We report here N.O. studies on Pt Mn alloys on which the magnetization and the resistivity have previously been measured by two of us /4/ /5/. Our purposes are to determine the shape of the molecular field distribution $P(H_m)$, and to study the remanent property.

EXPERIMENTAL CONDITIONS.— The concentrated alloys ($x \geq 40$ ppm) were prepared by diffusing the radioactivity inside the alloys which have been studied by magnetization /4/. The dilute alloys, quoted a and b, have a content of parasitic iron impurities respectively of 7 and 24 ppm. The gamma ray anisotropy $E(0)$ down to 3 mK were detected with an axial Ge(Li) detector parallel to the applied field ($H$) and with an equatorial NaI (TI) detector perpendicular to the applied field.

NUCLEAR ORIENTATION ON A SPIN GLASS.— Spin glass behaviour can be characterized by a local breakdown of the quantization axis defined in the paramagnetic regime by the applied field $H$. In order to describe the N.O. results, Compton et al. /6/ have derived a simple model where (i) the electronic moment is well polarized along the components ($H_m$) of the applied field ($H$) and the molecular field ($H_m$) assumed randomly oriented with a constant modulus. (ii) Along the local axis $H_m$, the nuclei are submitted to their saturation hyperfine field ($H_{hf}$) (sat).

If ($H_m$) $= 0$ the nuclei are submitted to a cylindrical symmetry and the gamma ray anisotropy of the oriented nuclei, is described by the wellknown formula:

$$E(\theta) = U_F B z P_2 \cos \theta + U_B B z P_2 \cos \theta$$

where $U_F$ and $U_B$ are pure nuclear constants, $B_z$ and $B_z$ are the nuclear orientation parameters related to the hyperfine coupling and $P_2$ and $P_2$ are the Legendre polynomial, $\theta$ being the angle between the quantization and detector axis. The occurrence of a spin glass regime leads to an almost equivalent expression. Taken into account the random orientation of $H_m$ and the strength of the ratio $a = H_m/H$, two reduction factors, $A_2$ and $A_4$, must be applied to the even coefficients of $E(\theta)$. More generally to any molecular field distribution $P(H_m)$ will correspond integrated reduction factors $A_2$ and $A_4$. We have firstly tried to fit the results to the following molecular field distributions. i) an Heisenberg type : $P(H_m) = \frac{1}{\pi} \frac{A}{H_m^2} \delta H_m$ 

ii) an Ising type : $P(H_m) = \frac{1}{\pi} \frac{A}{H_m^2} \delta H_m$

Secondly as two counters have been used perpendicular and parallel to the applied field, the $A_2$ and $A_4$ coefficients are simply related to the axial and equatorial anisotropy by the expressions:

$$A_2 U_F B_z = \frac{3E(0) - 2E(\pi/2)}{7}$$

$$A_2 U_B B_z = \frac{4}{7} \left[ E(0) + 2E(\pi/2) \right]$$

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We have thus a selfconsistent procedure to determine the best fitting of the data with an Heisenberg or an Ising distribution. To each experimental value \( A_2 \) and \( A_4 \) corresponds a value of \( \Delta_{(2)}^{(1)}(H) \) and \( \Delta_{(2)}^{(1)}(L) \), the best fitting must be obtained for the best agreement of \( \Delta_2 \) with \( \Delta_4 \).

Finally it must be emphasized that in the magnetic regime the coefficients \( A_2 \) and \( A_4 \) have always a positive sign for the Heisenberg or the Ising distribution.

**EXPERIMENTAL RESULTS.** The high field measurements performed on the dilute sample (\( x < 40 \text{ ppm} \)) have confirmed the value of the hyperfine coupling found by previous experiments /7/ /8/:

\[
H_{hf} = -400 \pm 10 \text{ kOe}
\]

This value is exactly that found for Mn in gold known as a S = 5/2 state with a \( g \) factor equal to 2. Above 15 mK, the experimental data between the samples (a) (b), and two other dilute samples (which are not yet analyzed) are in excellent agreement. Strong departure is found from the free spin \( H/2 \) limit which describes a zero Kondo-coupling.

An attempt /2/ to evaluate the Kondo coupling from the initial slope of the effective field versus the applied field above 15 mK leads to a value:

\[
T_K = 42 \pm 10 \text{ mK}
\]

in good agreement with \( T_K = 25 \text{ mK} \) from reference /9/, assuming a susceptibility law

\[
\chi = \mu_{\text{eff}}^2 / 3k_B T_K
\]

Below 15 mK, the breakdown of the symmetry defined by \( H \) is partly due to the content of residual magnetic impurities and to the unusual high crystalline anisotropy /8/. The 40 ppm sample shows strong departure from the single ion behaviour well above its ordering temperature (\( T_M \approx 3 \text{ mK} \)).

The concentrated samples of 0.5 and 1% show characteristic spin glass behaviour with scaling laws in \( H/x \). The table I represents the experimental value of \( A_2 \) and \( A_4 \) of the 0.5 percent sample for three different applied fields and gives the corresponding value of \( \Delta^{(2)}(x) / H \) obtained with a Heisenberg or an Ising fitting. The best fit, obtained for the Heisenberg model, leads to an half width \( \Delta_H \) equal to:

\[
\Delta_H = 8 \pm 1 \text{ kOe/\%}
\]

The ratio \( g \mu^2_{\text{eff}} / k_B T_M = 1.34 \) of the molecular field by the freezing temperature \( T_M \) is in agreement with the expression obtained by Sherrington

\[
| \mu_{\text{eff}}^2 / k_B T_M = 1.5 |
\]

**References**

/1/ Flouquet, J., To be published Prog. Low Temp. Physics VII (1978)


/6/ Compton, J.P., Williams, I.R., Wilson, G.V.H., 1978 Hyperfine structure and nuclear radiations (North-Holland-Amsterdam) 793


**Table I**

<table>
<thead>
<tr>
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<th>EXPERIMENTS</th>
<th>HEISENBERG</th>
<th>ISING</th>
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<tr>
<td>( H ) kOe</td>
<td>( A_2 )</td>
<td>( A_4 )</td>
<td>( \Delta^{(2)}(x) / H )</td>
</tr>
<tr>
<td>---------------</td>
<td>--------------</td>
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<tr>
<td>2.94</td>
<td>0.114</td>
<td>0.0074</td>
<td>1.2</td>
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<tr>
<td>5.73</td>
<td>0.255</td>
<td>0.067</td>
<td>0.68</td>
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<tr>
<td>11.85</td>
<td>0.384</td>
<td>0.330</td>
<td>0.46</td>
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An attempt is made to detect the remanent properties after a saturation of the thermoremanent magnetization. The thermoremanent anisotropy \( E_R(O) \) was found to be extremely low and to correspond to the picture of almost randomly oriented spins. For the Pt Mn_{0.8} alloys, \( E_R(O) \) was found equal to:

\[
E_R(O) = -0.25 \% \text{ at } T = 6 \text{ mK}
\]

The limit of the experimental resolution is near 0.25 %. A good reference is that for the same sample at \( H = 12 \text{ kOe} \); \( T = 6.9 \text{ mK} \); \( E(O) = 18 \% \).

Finally the study of a Pt Mn_{0.425} by N.O. confirms that for such a concentration the spin glass behaviour is not followed as i) the scaling law is not respected and ii) the \( A_4 \) coefficient has an unusual negative sign.