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THE EFFECT OF PRESSURE ON THE ONSET OF FERROMAGNETISM IN DISORDERED Pd Ni ALLOYS

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Abstract.—The Landau theory of phase transitions is taken as the basis for a simple model describing the magnetization of Pd Ni alloys. We find the critical concentration, \( c_0 \), around 3.7 at. % Ni. A small concentration of giant moments, centered (as shown by Chouteau) on groups of 3 or more Ni neighbour atoms, perturbs the ideal behaviour of the matrix. Introducing \( dc_0/dp \) as a single additional parameter we obtain a good fit of the pressure effects measured by Beille, up to 10 at. % Ni.

Among the weakly magnetic Ni alloys, Pd Ni seem to be the simplest ones because of the small value of \( c_0 \), the critical Ni concentration for ferromagnetism. The percolation limit is not yet reached and it is easy to number the Ni clusters of a given size. The more clear cut result of the magnetic measurements of Chouteau /1/ is that the groups of 3 or more Ni first neighbour atoms bear giant magnetic moments and polarize the surrounding matrix.

We propose here a very simple model where the matrix, considered as magnetically homogeneous, follows the Landau theory of phase transitions. Its interaction with the giant moments is described in the molecular field approximation /2/. This model applies equally well to VNi /3/, RhNi or PtNi (to be published). The magnetization, \( M \), is expressed by

\[
M = M_1 + M_2, \quad M_2 = \frac{NgJ\mu_B (H + XM_2)}{kT}
\]

The parameters \( A, B, \lambda, N \) and \( J \) can be extracted from experiment. Our analysis of existing data, in particular the measurements of Beille /4/, is in agreement with the result of Chouteau /1/ that

\[
3N = Nc \left[ 1 - (1-c)^{12} - 12 c(1-c)^{10} \right].
\]

We take \( 10\mu_B \) (i.e. \( J = 5 \)) as the mean value of the giant moments, and \( \lambda = 500 \text{ mole/emu} \) for the molecular field parameter, independently of the Ni concentration.

\( B \) can be considered as a constant; its inverse is approximately equal to the slope of the high field Arrott plots (\( M^2 \) vs. \( H/M \)). We chose \( B : 8 \times 10^{-4} \) (emu/mole). At low concentration, \( A \) is simply the inverse of the alloy susceptibility; the slight curvature of \( A(c) \), already visible on figure 1 below 1.5 at % Ni, is clearly related to the deviation from linearity of the concentration of single Ni impurities, \( c_1(c) = c(1-c)^{12} \).

Fig. 1 : Proposed variation of the Landau parameter \( A \) with Ni concentration, at \( T = 0 \) (see text).
In the weakly ferromagnetic alloys, above 4 at.% Ni, we have $|A| \lesssim (2\chi_{oo})^{-1}$, because of the presence of magnetic inhomogeneities ($\chi_{oo}$ is the differential susceptibility). In the calculations presented here, $A(c)$ was roughly approximated by the straight line of figure 1. The corresponding critical concentration is thus too high by about 0.5 at.% (see figures 2, 3 and 4). Following the Stoner-Edwards-Wohlfarth model of weak ferromagnetism, we write $A(T, c, p) = \alpha T^2 + \beta (c-c)$ with $c = c_{oo} + \gamma p$. The calculated magnetization, in fields up to 150 kOe is in good agreement with Beille's measurements, also at finite temperatures. Let us consider here, on figures 2, 3 and 4, the effect of hydrostatic pressure on the magnetic properties.

Fig. 2: Pressure derivative of the spontaneous magnetization versus Ni concentration. Points: Beille's experiments; solid curve: calculated (matrix + clusters); dashed curve: calculated (matrix alone).

Our single additional parameter, $dc_0/dp = 2 \times 10^{-4}$ kbar$^{-1}$ was chosen so as to give the right order of magnitude of the variation of the spontaneous magnetization with pressure, near 3 at.% Ni (figure 2). The experimental minimum (4) appears at the right concentration. The observed variation with pressure of the "alloy susceptibility", figure 3, and the Curie temperature, figure 4, (definitions in reference /4/) are also fairly well reproduced in spite of the simplicity of the model (no attempt was made to refine the choice of the parameters). It is obvious, from these last three figures, that the response of the matrix is strongly damped by the presence of the giant moments.

Fig. 3: Pressure derivative of the "alloy susceptibility" versus Ni concentration. Symbols and curves as on figure 2.

Fig. 4: Pressure derivative of the Curie temperature versus Ni concentration. Symbols and curves as on figure 2. (a) $H = 0$; (b) Deduced from high field Arrott plots, following Beille.

These curves can be compared with the results of the more elaborate model of Beille and Chouteau /4, 5/ which fails to reproduce the minimum of $dM_0/dp$ and the maximum of $d\chi_{all}/dp$, as well as the values of $dt_C/dp$ near $c_0$. 
References