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ONSET OF MAGNETIC ORDERING IN PdNi

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Abstract. - Spontaneous resistive anisotropy and ac susceptibility measurements have been used to investigate the appearance of magnetic order at low temperatures in PdNi.

Attempts to establish the presence of ferromagnetic ordering in magnetic systems are frequently based on fits of available data to scaling law predictions, viz

\[ m(h, t) = t^\beta F \left( \frac{h}{T - T_c / T_c} \right); \]

\[ \chi(h, t) = h^{(1/\delta - 1)} G \left( \frac{h}{T - T_c / T_c} \right) \]  

(1)

where \( h = H / T_c \), and \( t = (T - T_c) / T_c \), \( T_c \) being the zero-field ordering (Curie) temperature. Such an approach is based on the assumption that the measured response \( m(h, t) \) is dominated by that contribution arising from critical fluctuational (the singular component) rather than any regular (background) contributions. Generally speaking, in metallic alloys, this expectation is fulfilled when impurities with no orbital moment are introduced into the system i.e. Mn or Fe in Pd [1]. In the latter, critical effects can be seen in quite low applied fields [2]. By contrast the critical behaviour of Co in Pd cannot be studied in low field [3] because the “technical” contribution to the response (coherent rotation, domain wall motion, etc.) does not saturate in such fields, an effect that has been attributed to single ion spin-orbit coupling associated with a Co orbital moment [4].

The presence of the latter was inferred, in part, from observations of a spontaneous resistive anisotropy for Co and Ni but not for Fe or Mn in Pd [1].

Here we present a summary of a study of the ac susceptibility (\( \chi_{ac} \)) and the spontaneous resistive anisotropy (sra) carried out on numerous PdNi samples (containing between 2 and 5 at.% Ni). While the analysis of the ac susceptibility is indeed complicated by a regular contribution expected to accompany a sra associated with spin-orbit coupling, we demonstrate that a non-vanishing anisotropy can be observed through accurate measurements of the magnetoresistance in low applied fields (≤50 gauss). This enables the critical concentration for this system to be estimated directly (in low applied field the spin splitting polarisation is dominated by intrinsic not extrinsic effects). These two techniques are, therefore, to a considerable extent mutually exclusive; the ordering of S-state impurities produces sharply discernible features in \( \chi_{ac} \) but no sra, while the reverse is true for impurities with orbital degrees of freedom. It is the latter that can be exploited in PdNi.

Figure 1 shows the longitudinal (\( \rho_H \)) and transverse (\( \rho_L \)) magnetoresistance of a 4.5 at.% Ni sample measured at 1.5 K in fields up to 1 T, using an ac technique [4]. This sample has a Curie temperature \( T_c \approx 58 \) K, and the presence of a resistive anisotropy is clear below \( T_c \). Figure 2 reproduces measurements of \( \chi_{ac} \) (using a phase-locked susceptometer operating at 2400 Hz in a driving field of 50 mOe rms) in various static biasing fields; the presence of a cross-over line (a line along which the susceptibility in fixed static field exhibits a maximum, \( (\partial \chi_{ac} / \partial h)_{m} = 0 \)) is clear. This line is predicted from equation (1) to vary as [2]:

\[ t^{\gamma+\beta} \propto h, \quad \text{with} \quad \chi_{ac}(h, n) \propto h^{(1/\delta-1)} \]  

(2)

However the appearance of a substantial regular component in \( \chi_{ac} \) at low field is also evident in this figure; the critical peaks associated with this cross-over line cannot be resolved against this regular background below about 30 gauss. This means, for example, that estimates for exponents such as \( \delta \) cannot be made reliably as shown in figure 3. The (asymptotic) low-field estimate for \( \delta (\sim 4.1) \) therefore has considerable un-
monotonically with decreasing temperature down to 1.8 K (the lowest temperature that could be attained with the present apparatus); an analysis of its field dependent susceptibility is complicated by the same features evident in figure 2. The transport data however are unambiguous (Fig. 4), there is a small $\sigma$ evident in low field at 1.5 K which vanishes on warming to 4.2 K. This provides conclusive evidence that this sample orders magnetically above 1.5 K. A 2.3 at.% Ni sample does not.

Such problems become more acute as the Ni concentration is lowered towards a critical value of about 2.4 at.% necessary to establish ferromagnetism at low temperature [5]. A sample of this latter composition exhibits a zero field susceptibility which increases

Fig. 2. $\chi_{ac}$ versus temperature in various static fields (in Oe).

Fig. 3. Complications evident in evaluating the exponent $\delta$.

Fig. 4. Temperature dependence of the $\sigma$ in Pd-2.4 at.% Ni.