MAGNETIC MOMENTS AND INTERNAL FIELDS IN $Fe_8Ni_{72}P_{10}B_{10}$ [1])

KAMBERSKÝ, V.,[2]) KALVA, Z.,[2]) ZÁVĚTA, K.,[2]) Praha

The assumptions and results of a previously reported analysis of $M(H, T)$ dependence in as-quenched amorphous $Fe_8Ni_{72}P_{10}B_{10}$ performed in terms of a model including self-consistent random-direction effective fields acting on superparamagnetic clusters (in a paramagnetic matrix) are discussed from various aspects. Evidence is inferred for chemical inhomogeneity of the samples and for large $3d$ density of states (discussed in context of weak magnetism in Ni-rich glasses).

I. INTRODUCTION

Mean spontaneous magnetic moments $\bar{\mu}$ per transition metal (TM) atom are usually determined from $M(H, T)$ measurements extrapolated to $(H, T) = 0$. This is facilitated by the linearity of the M^2 vs H/M curves (Arrott—Belov—Kouvel or ABK plots) in many (uniform) ferromagnets. Slight deviations from linearity of the ABK plots were taken into account in quadratic extrapolation in Kaul's [1] careful systematic analysis of $\bar{\mu}$ in the $(Fe_xNi_{1-x})_{80}(Me)_{20}$ metallic glasses, with Me representing mixtures of B and P. The results of this analysis (regarding also previous extended studies; cf. [1] for references) were summarized in empirical rules which approximately determine the individual spontaneous moments on Fe and Ni atoms as

$$\bar{\mu}_{Fe}/\mu_B = n^0_{Fe} + 0.8(1 - x)$$
$$\bar{\mu}_{Ni}/\mu_B = n^0_{Ni} + 0.2x, \qquad (1)$$

where n^0_{Fe} and n^0_{Ni} only weakly depend on the kind of metalloid. In crystalline Fe_xNi_{1-x}, where (1) is supported by neutronographic evidence, $n^0_{Fe} = 2.2$ and $n^0_{Ni} = 0.6$; qualitatively, the first rule indicates that dilute Fe in Ni forms local moments of $3\mu_B$ which decrease by Fe—Fe interactions, while the second rule indicates that Ni moments are enhanced by Ni—Fe interactions; both rules are intuitively plausible in view of the disproportion in the net numbers of $3d$ holes in both atomic and metallic Fe and Ni. The presence of Me in metallic glasses slightly diminishes n^0_{Fe}, to 2.0 for Me = B and 1.85 for Me = P [1]; in contrast to crystalline Ni, n^0_{Ni} is zero for Me = P [1] and very close to zero even for Me = B ($n^0_{Ni} = 0.006$ was found in $Ni_{81.6}B_{18.4}$ [2]).

The determination (and even concept) of spontaneous magnetic moments appears to be non-trivial in low-Fe systems where uniform ferromagnetism gradually changes to partial ordering of finite clusters and, eventually, to paramagnetism. Extrapolation of $M(H, T)$ to $(H, T) = 0$ then substantially depends on the expected shape of ABK plots, which may be analytically prescribed or derived from suitable models. Since the two-component model of clusters interacting with a weakly magnetic matrix [3] many more or less refined models were compared with experimental results in literature. The purpose of the present paper is to comment on the assumptions employed and results obtained for a simple but apparently versatile model proposed in our recent report [4].

II. COMMENT ON THE RANDOM-DIRECTION MOLECULAR-FIELD MODEL

The model used for fitting [4] of ABK plots in $Fe_8Ni_{72}P_{10}B_{10}$ obtained by Kadlecova et al. [5] assumes a Pauli paramagnetic (or weakly ferromagnetic) matrix interacting by a Weiss mean field with the average magnetization of a set of superparamagnetic (presumably, Fe-rich) clusters; the clusters are supposed to see, in addition to the mean field of the matrix, local effective fields of magnitude proportional to the average absolute value of the static (expectation) cluster moment, but pointing into random directions.

The results simulate spin-glass behaviour when the Weiss field is neglected [6] or, more generally, asperomagnetic ordering with a single second-order phase transition and either zero or nonzero spontaneous magnetization in the ordered phase, depending on the relative amplitudes of the random and the Weiss fields [4] (the magnetization resembles that of re-entrant systems [7] which, however, are supposed to exhibit two phase transitions [8]).

The point to be discussed in this paragraph is the origin of the random-direction effective fields in context of the results obtained for their maximum magnitude from the fitting [4]. This magnitude (H_{iR} 2.7 T) was tentatively compared with the effective field of local anisotropy, H_{KR}, acting on relatively large Fe-rich clusters: from Neel's theory of pair ordering [9] and simple statistics, the latter may be expected to attain the same order of magnitude (≈ 3 T).

In the formulation of the model [6, 4], H_{iR} is an effective interaction (exchange) field, while local anisotropy is only implicitly assumed to affect the original stages of the "freezing" of the cluster moments in directions substantially different from that of the external (and the Weiss) field. It has been

[1]) Contribution presented at the 8th Conference on Magnetism, KOŠICE 29. 8.—2. 9. 1988

[2]) Inst. of Physics, Czechosl. Acad. Sci., PRAHA, Czecho-Slovak Federative Republic

checked separately [6] that random anisotropy alone, as an axial perturbation with two energy minima in opposite directions, does not essentially affect the ordering process (since even strong anisotropy only confines Heisenberg spins to an Ising subspace; cf. also [10, 11]).

The random field in the model might, perhaps, alternatively represent direct but non-ergodic effects of local anisotropy envisaged in the original Néel theory of rock magnetism [10], in which only one (the nearest) energy minimum of the two is explicitly considered while the other (more distant) is neglected as unattainable (in realistic times). In such interpretation we find, however, no off-hand argument for selfconsistency in the ordering parameter representing the absolute value of the frozen moment, which is essential in the model. In the Néel theory non-ergodicity steps in at temperatures determined externally, by the Arrhenius relations for activated processes. For further investigation of possible anisotropy effects (and of the coincidence between H_{iR} and H_{KR}) it may be useful to combine Néel's kinetic theory with the spherical easy-direction distributions used in the discussed models [6, 4, 10] (but not in the Néel theory and its extensions [12]).

III. COMMENTS ON THE MEAN ATOMIC MOMENTS

From the fitting for $Fe_8Ni_{72}P_{10}B_{10}$ [4] we have determined the average spontaneous moment of the clusters (besides the matrix) as 0.325 μ_B/atTM, i.e., 3.25 μ_B/at Fe if all Fe were in the clusters. Since this is more than expected for Fe from previous evidence, some moment in the cluster phase must be carried by Ni. Assuming that the moment is Fe-induced according to the empirical relations (1), we get from them $x_c = 0.12/y$ for the Fe concentration x_c in the cluster phase if $y < 1$ is the (unknown) concentration of this phase in the sample. This is well compatible with the implicit assumption of chemical inhomogeneity ($x_c > x = 0.1$).

The fitting was inconclusive in the parameter determining the spontaneous ferromagnetic moment of the matrix alone [4], apart from that induced by the Weiss field of the clusters. The latter, however, corresponds to the matrix susceptibility $\chi_m = \mu_B^2 Z_{ef}$, with $Z_{ef} = 15\ \mathrm{eV}^{-1}$/at Ni representing the exchange-enhanced (effective) density of states, quite considerably higher than the actual density of states $Z(0) \approx 3.5\ \mathrm{eV}^{-1}$/as expected for crystalline Ni. The only inference to be made from this finding (resulting, qualitatively, from a very large high-field susceptibility at all temperatures [5]) is some evidence against the interpretation of the lack of ferromagnetism in Ni-rich glasses as a result of the absence of 3*d* holes (3*d* band filling [1]).

While the concept of an electron charge transfer from Me onto TM atoms (which would render ionic compounds, with TM anions) is strongly contradicted by the metallic character of the glasses [13] and by calculations of compensating (screening) effects [14], it is still conceivable that the number of 3*d* holes available in crystalline Ni might be further reduced by alloying with the metalloid, as a result of mutual shifts of 3*s* and 4*sp* levels. However, such reduction (and shift) as seen between atomic and crystalline Ni (as well as Fe) is generally ascribed to delocalization; hence it is hard to see that alloying with he metalloid, adding 2(3)*sp* channels to 4*sp* but not 3*d* itinerancy, should further diminish the 3*d* energy (relative to 4*sp*). On the other hand, it is very likely that the increased proportion of 3*d*-*sp*-3*d* hybridisation (compared to the 3*d*-3*d* itinerancy) in the glasses just suppresses the Hubbard type correlation (energetically unfavourable for the broad-band *sp* contribution), which is sufficient for the transition from strong ferromagnetism in crystalline Ni to weak ferromagnetism [2] or even paramagnetism in Ni—Me glasses. Computations analogous to those recently reported for Fe—B glasses [15] might elucidate this point.

REFERENCES

[1] Kaul, S. N.: IEEE Trans. Magn., Mag-*17* (1981), 1208.
[2] Kaul, S. N., Rosenberg, M.: Phys. Rev. *B25* (1982), 5863.
[3] Acker, F., Hugenin, R.: J. Mag. Magn. Mat. *12* (1979), 58.
[4] Kambersky, V., Kalva, Z., Zaveta, K.: Phys. Stat. Sol. (b) *143* (1987), 249.
[5] Kadlecova, J., Handstein, A., Zaveta, K.: Phys. Stat. Sol. (a) *93* (1986), 213.
[6] Nozar, P., Sechovsky, V., Kambersky, V.: J. Mag. Magn. Mat. *69* (1987), 71.
[7] Geohegan, J. A., Bhagat, S. M.: J. Magn. Mat. *25* (1981), 17.
[8] Gabay, M., Toulouse, G.: Phys. Rev. Lett. *47* (1981), 201.
[9] Neel, L.: J. Phys. Radium *15* (1954), 225.
[10] Neel, L.: Ann. Geophys. *5* (1949), 99.
[11] Harris, R., Plischke, M., Zuckermann.: Phys. Rev. Lett. *31* (1973), 160.
[12] Wohlfarth, E. P.: Physica *86—88B* (1977), 853; J. Phys. F *10* (1980), 1241.
[13] O'Handley, R. C.: in *Amorphous Metallic Alloys*, Luborsky, F. E. ed., Butterworths, London 1983.
[14] Watson, R. E., Bennett, L. H.: in *Theory of Alloy Phase Formation*, Bennett, L. H. ed., New York 1980.
[15] Krompiewski, S., Krey, U., Ostermeier, H.: J. Mag. Magn. Mat. *69* (1987), 117.

Received September 16th, 1988
Accepted for publication November 8th, 1988

МАГНИТНЫЕ МОМЕНТЫ И ВНУТРЕННИЕ МОМЕНТЫ В $Fe_8Ni_{72}P_{10}B_{10}$

В работе с разных точек зрения обсуждаются предположения и результаты недавно опубликованного анализа M(H, T) зависимости в аморфных $Fe_8Ni_{72}P_{10}B_{10}$ сплавах. Анализ был проведен в терминах модели, включающей самосогласующиеся эффективные поля со случайной ориентацией, действующие на супермагнитные скопления (в парамагнитной матрице). Даны доказательства химической неоднородности в образцах и для большой 3d плотности состояний.