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NEUTRON SCATTERING STUDY OF THE MAGNETIC CORRELATIONS OF IRON RICH Fe-Zr GLASSES

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Small angle neutron scattering (SANS) and polarized-beam spin rotation measurements show that amorphous $\text{Fe}_{90}\text{Zr}_{10}$ does not exhibit conventional long range ferromagnetic order below T_c . The SANS measurements show the existence of two characteristic length scales: one provides evidence of relatively large spin clusters, while the other is characteristic of the spin dynamics.

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Extensive experimental evidence from bulk susceptibility and magnetization, as well as Mössbauer, experiments has suggested that the iron-rich Fe-Zr glasses of concentrations near $\text{Fe}_{90}\text{Zr}_{10}$ are not conventional ferromagnets. It has been proposed [1] that below a transition temperature " T_c " they become "wandering axis ferromagnets", where the spins are correlated only over relatively short distances, and that at a lower temperature " T_F " the transverse components of their spins freeze to form a "spin canted" (also called "asperomagnetic") phase.

In order to obtain a better understanding of the magnetic correlations of $\text{Fe}_{90}\text{Zr}_{10}$ we have performed small angle neutron scattering (SANS) and polarized-beam spin rotation experiments on amorphous ribbons of $\text{Fe}_{90}\text{Zr}_{10}$. These ribbons, approximately 25 μm thick and 0.5 cm wide, were wound on aluminum frames to form a flat platelike geometry. The SANS experiments were performed at the National Bureau of Standards Reactor using 8 Å neutrons and wave vectors $0.008 \text{ Å}^{-1} \leq Q \leq 0.06 \text{ Å}^{-1}$. A high temperature background was subtracted in order to obtain the magnetic intensity I. Figure 1 shows the plot of $1/I$ vs. Q^2 at selected temperatures. The data exhibit a Lorentzian Q-dependence for large Q's, but show an abrupt change in curvature for Q smaller than about 0.03 Å^{-1} , primarily at the higher temperatures and even above T_c . This functional form

indicates that there are two length scales present in the system, as will be discussed below.

Within the quasistatic approximation (integral over all inelastic processes) the SANS cross section is proportional to the Fourier transform of the instantaneous spin-spin correlation function. For an ideal ferromagnet at $T > T_c$ this cross section is a Lorentzian in Q :

$$I(Q) = \frac{A}{Q^2 + \kappa^2}, \quad (1)$$

where κ is the inverse of the correlation length ξ . Below T_c this cross section becomes the sum of two Lorentzians which correspond to fluctuations transverse and parallel to the direction of the spontaneous magnetization. Departures from Lorentzian lineshapes are observed in systems where spin frustration effects or random anisotropy fields produce a spin-glass-type behavior. We have analyzed our data using a cross section that is the sum of a Lorentzian and a function that represents the scattering from a number of independently frozen spin clusters having a Maxwellian distribution of Guinier radii [2]:

$$I(Q) = \frac{A}{Q^2 + \kappa^2} + \frac{B (\kappa^2)^{z-1.5}}{(Q^2 + \kappa^2)^z}. \quad (2)$$

A new spin correlation length ξ_z , associated with the second term in this cross section can be defined as the value R at which its Fourier transform $S(\kappa R)$ reduces to $1/e$ of $S(0)$. The advantage of using this form of the cross section is that its second term is very general, at the expense of introducing the extra parameter z . When $z = 2$ this term becomes a Lorentzian squared and ξ_z is simply $1/\kappa$. When $z \rightarrow \infty$ this term becomes a Dirac delta (the ferromagnetic scattering function). In particular, a large finite value of z allows us to account for the sharp change in curvature at low Q in the plot of $1/I$ vs Q^2 observed in our experiments. The solid lines in figure 1 are the results of the least-squares fit of Eq. (2) to the shown data. It can be seen that the agreement is excellent. From our analysis we found two correlation lengths: ξ for the Lorentzian term and ξ_z for the $(\text{Lorentzian})^z$ term. Figure 2 shows the temperature dependence of these correlation lengths. The shorter length, ξ , exhibits a cusp at T_c and is ascribed to the spin dynamics, while the larger length, ξ_z , presumably indicates the presence of relatively large (≈ 400 Å) spin clusters that do not disorder above T_c . For $T < 50$ K $z \approx 2$ and the data can then be adequately represented by a Lorentzian + Lorentzian squared function characteristic of a frozen spin cluster system.

In recent TEM investigations on amorphous films of $\text{Fe}_{90}\text{Zr}_{10}$, Senoussi et al [3] have found evidence

of magnetic domains (as large as $50\text{ }\mu\text{m}$) which are much larger than the correlated lengths found in our SANS experiments. These results, however, do not preclude the possibility of static spin fluctuations within the domains themselves. We also remark that neutron scattering data are more representative of the bulk of the sample while the TEM experiments might be more sensitive to surface effects.

We have also measured the susceptibility of $\text{Fe}_{90}\text{Zr}_{10}$ using a polarized-beam spin rotation technique [4]. The results are shown in Figure 3 and are the result of measurements made in a 5 Oe field, which was also the cooling field from above T_c . The susceptibility shows a sharp peak at the same temperature where ξ , from the SANS analysis, and the bulk susceptibility exhibit maxima: $T_c = 227\text{ K}$. Below T_c , the susceptibility decreases sharply and is constant below about 140 K. These data were obtained on a sample made of one thickness of parallel ribbons. The susceptibility obtained by this method is completely analogous to that measured by conventional bulk techniques, and reflects a behavior expected from a cluster spin glass and not from a ferromagnet.

From our analysis we conclude that the spin order in $\text{Fe}_{90}\text{Zr}_{10}$ below T_c is that of a non conventional ferromagnet. It has been suggested that this unusual spin ordering is a consequence of strong competition between ferromagnetic and

antiferromagnetic exchange interactions derived from
a distribution of Fe-Fe nearest neighbor distances

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REFERENCES

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- [1] D. H. Ryan, J. M. D. Coey, E. Batalla Z. Altounian, and J. O. Strom-Olsen, Phys. Rev. B35 (1987) 8630, and references therein.
- [2] A. Guinier and G. Fournet, *Small-Angle Scattering of X-Rays* (Wiley, New York, 1955) Chapter 4, section 4.4.2.
- [3] S. Senoussi, S. Hadjouj, P. Jouret, J. Blotte, and R. Formeaux, J. Appl. Phys. 63 (1988) 4086.
- [4] N. Stusser, M. Th. Rekvelde, and T. Spruijt, Phys. Rev B31 (1985) 5905.

FIGURE CAPTIONS

FIGURE 1. Inverse intensity vs. Q^2 for selected temperatures both above and below $T_c = 227$ K. The data display a Lorentzian dependence (Eq. (1)) at the higher Q 's, with an anomalous drop off at low Q 's even above T_c . In the vicinity of T_c this decrease is somewhat masked. The continuous upward curvature of the 10 K data is characteristic of a spin frozen state. Note: The curves have been displaced upward by one scale unit on the y axis for successive temperatures below 240 K.

FIGURE 2. The two length scales obtained from the data of figure 1 using the Lorentzian plus (Lorentzian)^{power} analysis discussed in the text. The longer length scale is ascribed to static ordered clusters, while the shorter length scale is attributed to the dynamics.

FIGURE 3. Susceptibility data obtained from polarized-beam spin rotation measurements. The susceptibility peaks at the same temperature as ξ (from the SANS results), and below T_c drops sharply in marked contrast to the behavior which would be expected of a ferromagnet.

FIGURE 1

FIGURE 2