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SPIN DYNAMICS OF AMORPHOUS $Fe_{0.86}B_{0.14}$

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A high resolution neutron inelastic scattering experiment has been performed in order to study the spin dynamics of amorphous $Fe_{0.86}B_{0.14}$, which exhibits Invar properties. Spin waves were observed in the wave-vector range $0.05 \leqq q \leqq 0.13$ Å^{-1}, at temperatures between 0.53 and $0.93 T_c$. The spin-wave energies were well described by a quadratic dispersion relation and the stiffness constant renormalized with temperature as $D = D(0)[1 - a(T/T_c)^{5/2}]$. The q and T dependence of the spin-wave intrinsic linewidths was confirmed to be consistent with the $\Gamma \alpha q^4[T \ln(kT/E)]^2$ form predicted from the two magnon interaction theory of a Heisenberg ferromagnet. There are no anomalies in the spin-wave lifetimes at long wavelengths which appear to relate to the Invar effect seen in $Fe_{0.86}B_{0.14}$.

1. Introduction

A complete understanding of the dynamical properties of Invar type ferromagnets is still a problem of current interest. Early neutron inelastic scattering studies [1–3] on the amorphous alloy $Fe_{0.86}B_{0.14}$ showed that the spin-wave energies at small q obeyed the usual dispersion relation expected for a nearly ideal isotropic ferromagnet:

$$E = \Delta + Dq^2 , \qquad (1)$$

where Δ is a very small anisotropy gap which originates in this alloy from the dipole interaction, D is the exchange stiffness constant and q is the magnon wave vector. The spin-wave stiffness constant "D" renormalizes according to the equation

$$D(T) = D(0)(1 - a(T/T_c)^{5/2}) , \qquad (2)$$

as predicted from the two magnon interaction theory of a Heisenberg ferromagnet [4]. However, the stiffness constant obtained from neutron scattering is almost twice as large as that derived from the $T^{3/2}$ coefficient of the magnetization. Such a discrepancy is apparently an intrinsic dynamic property of the Invar state [1–3], and indicates that there are other low-lying magnetic excitations of importance in these materials.

In addition to the spin wave energies, the intrinsic lifetimes in Invar systems have been studied in some detail. Ishikawa et al. [1] have reported that the spin wave damping is anomalous in amorphous $Fe_{0.86}B_{0.14}$, as well as in the crystalline Invar systems $Fe_{65}Ni_{35}$ and Fe_3Pt [5]. They have reported the empirical relation

$$\Gamma = [\Gamma_0 + aT^{\alpha}]q^2 , \qquad (3)$$

with $\alpha \leqq 1$, instead of the usual form

$$\Gamma \alpha q^4[T \ln(kT/E)]^2 \qquad (4)$$

that is predicted from the two magnon interaction theory of a Heisenberg ferromagnet [6]. On the other hand, our own measurements [3], taken with somewhat better resolution over a larger region of q and E, showed that the small q spin-wave linewidths in this system were in good agreement with eq. (4). However, for both measurements the intrinsic linewidths were smaller or at most comparable to the energy resolution.

In order to resolve this discrepancy, and to determine whether our analysis procedures are

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reliable, we have carried out new measurements with considerably higher resolution, over a larger range of q and T. These measurements have confirmed our previous conclusion that the spin-wave linewidth data are consistent with the two magnon interaction theory of a Heisenberg ferromagnet. Thus there do not appear to be any anomalies in the long wavelength spin-wave linewidths which can be attributed to the Invar property.

2. Experiment and results

A new sample of $Fe_{0.86}B_{0.14}$ was prepared in ribbon form by the planar flow casting technique in vacuum. Boron enriched to 98.5% ^{11}B was used to reduce the neutron absorption. Approximately 22 g of ribbon were wound between two copper posts to produce a flat plate-like sample which was placed in a vacuum furnace designed to eliminate air scattering. The neutron scattering measurements were taken on the HB-3 triple axis spectrometer at the High Flux Isotope Reactor (HFIR) at the Oak Ridge National Laboratory (ORNL). The instrumental parameters are listed in the first column of table I, which also lists the parameters used in the previous experiments [1–3]. Beryllium crystals of small mosaic spread (~16′) were used as monochromator and analyzer. The incident energy was fixed at 14.797 meV and a pyrolytic graphite (PG) filter was placed after the monochromator in order to suppress higher order wavelength contaminations. Soller slit collimators of 60′–10′–10′–60′ were used to produce a FWHM energy resolution of 0.22 meV at the elastic position. The measurements were made near the forward (0, 0, 0) beam position as

Table I
Comparison of the instrumental parameters of three neutron inelastic experiments on amorphous $Fe_{0.86}B_{0.14}$

	This work	Ref. 3	Ref. 1
Fixed E_i (meV)	14.80	13.95	14.5
Monochromator	Be(101)	PG(002)	PG(002)
Analyzer	Be(002)	PG(002)	PG(002)
E resol.* (meV)	0.22	0.35	0.60 †
Vert. resol. ($Å^{-1}$)	0.1	0.2	0.2 †
Resol. volume (Normalized)	1.0	5.2	13.6 †

* FWHM at elastic position.
† Estimated.

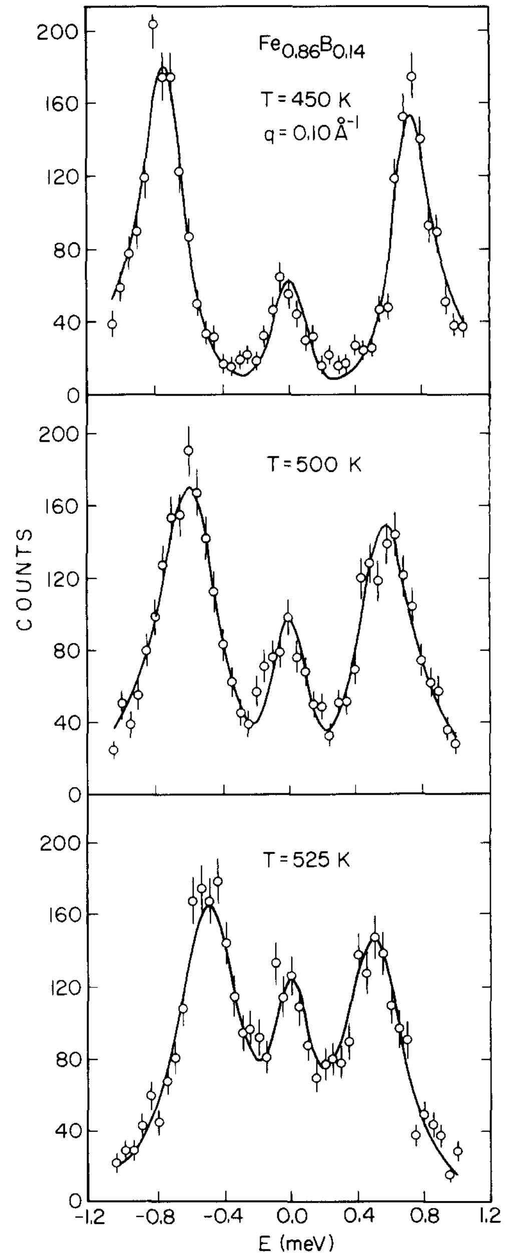

Fig. 1. Temperature dependence of spin-wave excitations in $Fe_{0.86}B_{0.14}$ at $q = 0.10\ Å^{-1}$. The solid lines are the least-squares fit to the convolution of the cross section with the instrumental resolution (see text). The central peak is due to incoherent scattering from the sample, holder and furnace.

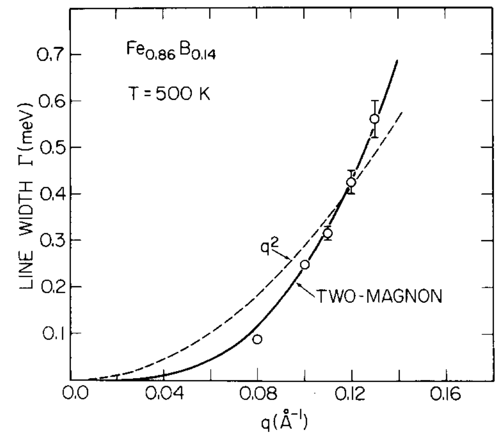

Fig. 2. The intrinsic spin-wave linewidths as a function of q at $T = 500$ K. The solid line is the $q^4 \ln^2(kT/E)$ dependence expected from the two magnon interaction theory. The results are not in agreement with the q^2 dependence (dashed line) reported by Ishikawa et al. [1, 5].

required by the amorphous state of the sample. The data were taken in the constant-q mode and the wave-vectors examined were in the range $0.05 \leqq q \leqq 0.13$ Å^{-1}. The temperatures under study ranged from 300 K ($0.53 T_c$) to 525 K ($0.93 T_c$), where well defined spin waves were observed.

In analyzing the data, spin-wave energies and damping information were obtained by convoluting a theoretical cross-section with the four dimensional instrumental resolution and least-squares fitting to the observed spectra. Fig. 1 shows our data at $q = 0.10$ Å^{-1} for temperatures of 450, 500 and 525 K. The solid lines are the result of the fit to a double Lorentzian spectral weight function with a delta function central peak, convoluted with the instrumental resolution. The central peak is due to incoherent scattering from the sample, holder and furnace, and its width is just the instrumental energy resolution. A constant background has been subtracted from the data shown in this figure. Plots of the spin-wave energies vs. q^2 showed agreement with the dispersion relation (1) at all temperatures under study. The spin-wave stiffness constant $D(T)$ was found to renormalize in accordance with eq. (2), with $D(0) = 123.5 \pm 1.8$ meV Å^2 and $a = 0.83 \pm 0.02$. These values are in reasonable agreement with the values obtained in the previous studies [1–3], which were made on different samples of the same nominal concentration. The value of $D(0)$ is to be contrasted to $D_{mag} = 65$ meV Å^2 calculated from the $T^{3/2}$ term in the low-T magnetization [7]. This discrepancy is common to other known Invar systems as discussed above.

The spin-wave intrinsic linewidths (Γ) have been plotted against q and fitted to the two magnon interaction form of eq. (4) and to the q^2 dependence of eq. (3), as shown in fig. 2 for $T = 500$ K. The solid line is the result of the fit to the two magnon interaction result (eq. (4)), while the dashed line is the result of the fit to the q^2 dependence of eq. (3). It is evident from this figure that the linewidth data are consistent with the two magnon interaction theory of a Heisenberg ferromagnet at this temperature. Similar agreement with the theory was observed at all the other temperatures studied.

In summary we find no anomalies in the long wavelength magnon lifetimes which appear to result from the Invar effect in $Fe_{0.86}B_{0.14}$.

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