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INVESTIGATION OF THE PARAMAGNETIC PHASE OF BCC IRON USING POLARIZED NEUTRON SCATTERING

by

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Abstract

Recent neutron scattering experiments performed at Brookhaven on Ni and Fe (4%-Si) above T_c have demonstrated that a simple paramagnetic scattering function

$$S(Q\omega) \propto \frac{1}{\kappa_1^2 + q^2} \quad \frac{\Gamma}{\Gamma^2 + \omega^2}$$

can explain the persistent spin wave ridges previously reported by Lynn and Mook. We present our new polarized beam results on pure Fe and describe in some detail the special problems associated with the unpolarized beam studies of magnetic cross sections at high temperatures.

A series of neutron scattering experiments[1-3] have recently been carried out at Brookhaven on Ni and Fe (4%-Si) above the Curie temperatures T_c, where persistent spin waves have previously been reported by Lynn and Mook[4,5]. New data are shown to be described by a simple scattering function

$$S(Q,\omega) \propto S_o \quad \frac{1}{\kappa_1^2 + q^2} \quad \frac{\Gamma}{\Gamma^2 + \omega^2} \tag{1}$$

which is valid for a wide range of Q,ω and T and reproduce qualitatively the relatively sharp peaks observed in constant E scans[4,5]. This scattering function was previously established for Ni and Fe near the critical region[6,7]. We have demonstrated that the same function is valid for a much wider range then previously assumed. This happens to show a relatively sharp peak in constant ω slices.

The cross sections given in Eq. 1 are Lorentzian in ω, for a given q, and therefore do not show any peak in constant Q scans. Typical data for Fe (4%-Si) obtained via polarized neutrons are shown in Fig. 1. The inset in Fig. 1(b) is just Fig. 10 of Ref. 5 which corresponds to a constant Q scan obtained via unpolarized neutron studies on an Fe(12%-Si) crystal with wave vector (0,1.152, 1.152) ($q = 0.47Å^{-1}$) and $T = 1.28\ T_c$. This is the only experimental disagreement between our data and the Oak Ridge data; all of our constant E scans are in good agreement with theirs. We have been informed[8] that Fig. 10 presented by Lynn was put together by collecting constant E scans and substracting various backgrounds. The following observations may point to the danger of utilizing unpolarized neutron beam at high temperatures for magnetic studies.

In Fig. 2, we depict some examples of our own unpolarized beam data obtained above and below T_c. The very important features of these data are the additional multi-phonon cross sections below the regular longitudinal phonons around 16 meV (see also Fig. 1(b)). Notice how strongly temperature dependent this broad ridge is around 5 meV. We know, from Fig. 1, how much of the total cross section is magnetic in origin. Even though Lynn's experiments utilized the ^{54}Fe isotope, which has much smaller nuclear cross sections, it is quite difficult to perform a reliable background subtraction because of this multi-phonon effect.

We have first suspected that these large additional cross sections are related to Si alloying of our crystal. This speculation originates from the fact that the previous phonon data[9] taken on pure Fe were extremely clean without any additional bumps below the longitudinal phonon regions. Further experiments at different neutron energies have proved that the deciding factor is not the 4%-Si concentration but is the neutron energy utilized. If one collects data at relatively low E_f (for example 14.7 meV) with relatively tight collimations, then one observes only true phonons. Once the neutron energy is increased to 60 meV or higher, the multi-phonon cross sections increase dramatically. We were unaware of this effect before our experiments. It is all the more impressive that the polarization analysis completely eliminates this difficulty as we have demonstrated in Fig. 1.

Now we present our new polarized beam results of pure Fe in Fig. 3. These correspond to flipper ON data in Fig. 1 and are obtained at the same q values. The temperature selected was only 22°K above T_c because of the nearby α-γ phase line. We argue that if the persistent spin wave ridge exists at higher temperature, then it must also exist near T_c. The background shown is rather arbitrary but there is little doubt concerning the Lorentzian nature of the cross section; no enhancement was observed at the "ridge" shown by the arrow.

We are now extending our polarized beam measurements to higher q values. When the magnetic cross sections get smaller, then it becomes essential to resort to the more elaborate data correction mode; namely to take the difference of horizontal and vertical fields as has been previously done at ILL, Grenoble[10]. These results will be reported shortly.

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Figure Captions

Fig. 1 Constant Q scans of Fe(4%-Si) at (a) (0,1.07, 1.07) for T = 1.1 T_c and (b) (0, 1.15, 0, 1.15) for T = 1.2 T_c. The broken curve represents non-spin flip and the solid line spin flip scatterings. The arrow points toward the expected persistent spin wave ridge. Inset in (b) is copied from Fig. 10 of Ref. 5 by Lynn. After Wicksted et al.[2]

Fig. 2 Constant Q scans obtained using unpolarized neutrons in Fe(4%-Si) at (0, 1.15, 1.15). Solid circles represent data obtained at T_c + 75 K while open triangles represent data obtained at T_c - 225 K. The large peaks at the right are the LA phonons while the broader peaks represent multi-phonon processes.

Fig 3 Constant Q scans of the paramagnetic scattering in pure Fe at (1.15, 1.15, 0) for T = 1.02 T_c. The open circles represent spin flip scattering. The arrow points towards the "persistent spin wave ridge".

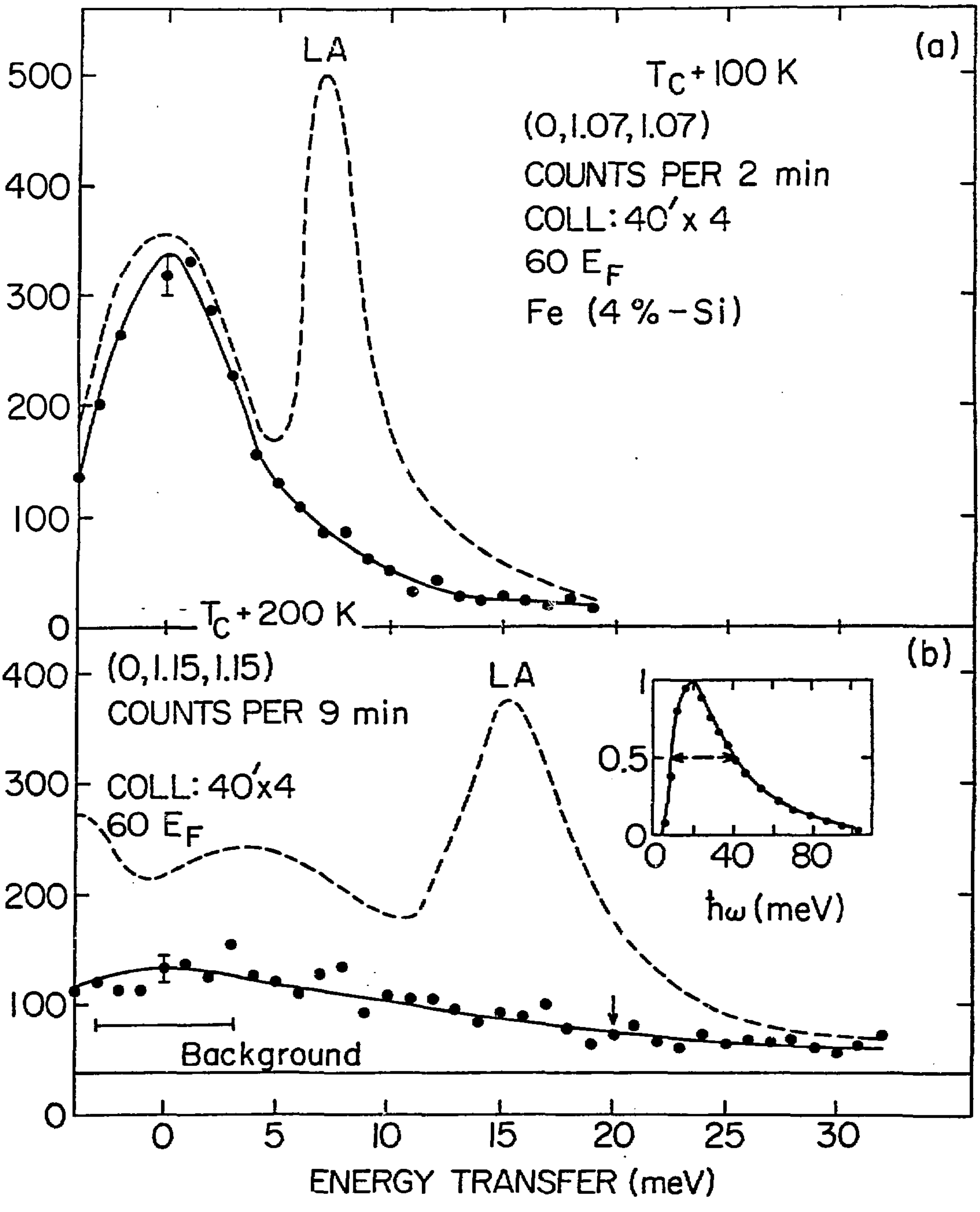
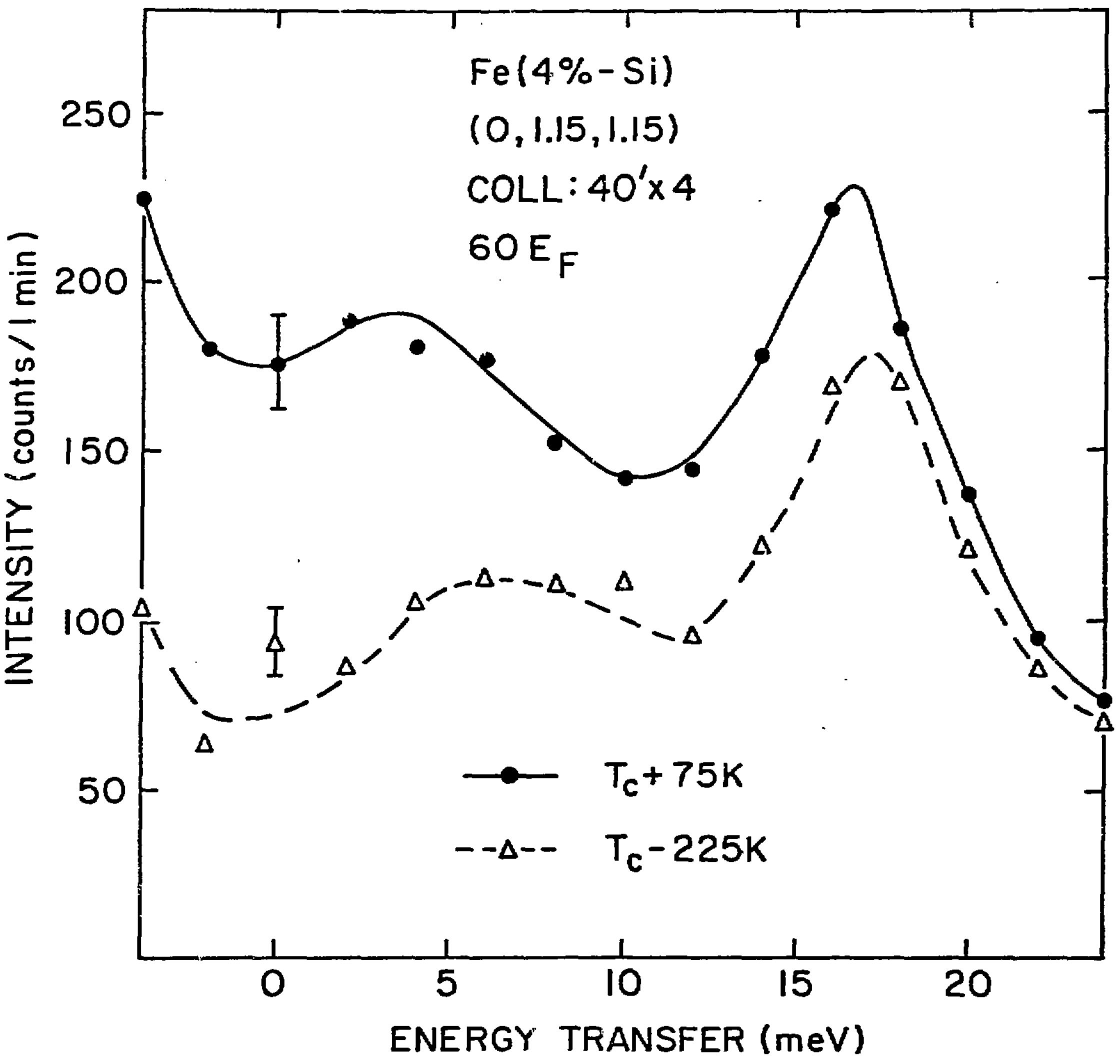
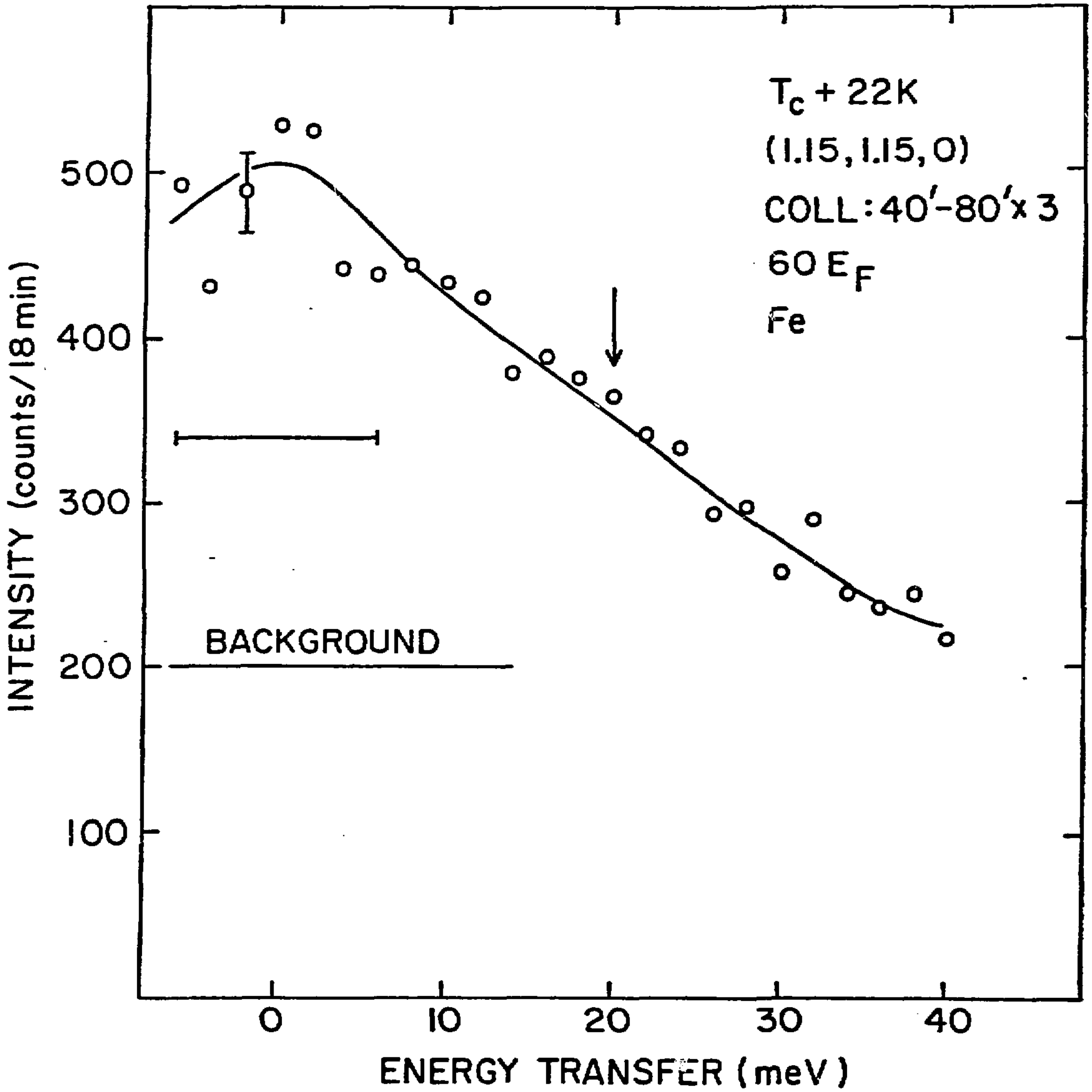

LA
(a)
T_C + 100 K
(0,1.07,1.07)
COUNTS PER 2 min
COLL: 40′ x 4
60 E_F
Fe (4 % - Si)
T_C + 200 K
(b)
(0,1.15,1.15)
COUNTS PER 9 min
COLL: 40′x4
60 E_F
LA
Background
ħω (meV)
ENERGY TRANSFER (meV)

FIGURE 1



Fe(4%-Si)
(0,1.15,1.15)
COLL: 40'x4
60 E_F
INTENSITY (counts/1 min)
250
200
150
100
50
0
5
10
15
20
ENERGY TRANSFER (meV)
T_c+75K
T_c-225K

FIGURE 2



T_c + 22K
(1.15, 1.15, 0)
COLL: 40′-80′x 3
60 E_F
Fe
BACKGROUND
INTENSITY (counts/18 min)
500
400
300
200
100
0
10
20
30
40
ENERGY TRANSFER (meV)

FIGURE 3