CONF-910903--5

DE91 015328

MAGNETIC EXCITATIONS IN THE TRIANGULAR ANTIFERROMAGNET Mn_3Sn

P. Radhakrishna

Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore, India

and J. W. Cable

Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831-6393, U.S.A.

ABSTRACT

The intermetallic compound Mn_3Sn has a triangular spin configuration below the Néel point at 420 K. Below 230 K, this triangular spin arrangement remains within each hexagonal layer, but the spins rotate about the c axis with a period of about 10 c_0. We have studied the magnetic excitations of this itinerant electron antiferromagnet along high-symmetry directions at temperatures above and below the helical phase transition T_h. At 295 K, the spin-wave dispersion is approximately linear in q along {100} and {110} and quadratic in q along the {1,0,ζ} and {1,1,ζ} directions. The spin-wave energies at 295 K can be described by $(\hbar\omega)^2 = \Delta^2 + A^2q^2$ and $\hbar\omega = \Delta + Bq^2$ where the anisotropy gap Δ = 4.3 meV, $A \simeq$ 100 meV-Å for {100}, $A \simeq$ 135 meV-Å for {110}, and B = 130 meV-Å^2 for {1,0,ζ} and {1,1,ζ}. Below T_h, the zone center shifts to the satellite positions of the helical structure, and the dispersion along {1,0,ζ} becomes linear in q with $\hbar\omega \simeq 95\,q$ [meV].

The intermetallic compound Mn_3Sn has a hexagonal crystal structure with lattice constants at room temperature of $a_o = 5.665$ and $c_o = 4.531$ Å. [1] There are six Mn atoms per unit cell. Below $T_N = 420$ K, a triangular antiferromagnetic order develops in which nearest-neighbor spins within the basal planes are oriented at 120°, while ferromagnetic alignment occurs for those spins along the c axis connected through an inversion center. [1,2,3] Since the magnetic and nuclear unit cells are the same, the antiferromagnetic and the nuclear Bragg peaks superimpose. Below 230 K, another magnetic phase transition occurs for which the basal plane spin arrangement remains, but the spins rotate about the c axis with a period of about 10 c_o. In this phase, the antiferromagnetic reflections appear as satellite peaks around each nuclear peak. The occurrence of this second magnetic transition appears to depend on the heat treatment of the compound.

Recently, Radhakrishna and Tomiyoshi [4] studied the magnetic excitations of this compound at temperatures above and below the helical phase transition. Their room temperature results show an anisotropy gap of about 4.1 meV and essentially linear dispersion in the {100} and {110} directions with the velocity in the {110} direction being about 35% higher than {100}. Because of low intensities, their low-temperature data were limited to energy transfers below 10 meV and, in this region, constant energy scans along $Q = (1,0,\zeta)$ showed an unresolved three-peak structure with the outer peaks close to the modulation wave vector of the helical structure, $\tau \simeq (0,0,\pm 0.1)$, and with essentially vertical dispersion. This paper describes an extension of those measurements to higher energy transfers to better resolve the dynamic behavior of Mn_3Sn. The sample is the same as that used in Ref. 4; it is non-stoichiometric with composition $Mn_{3.2}Sn$.

Neutron inelastic scattering measurements were made on the triple-axis spectrometers at the HFIR located at the Oak Ridge National Laboratory. Data were obtained around the (100), (101), and (110) Bragg positions for the triangular

antiferromagnetic phase at T = 295 K and around the (100) and (101) peaks for the helical phase at T = 12 and 100 K. Most of the data were obtained in the constant-E mode with pyrolytic graphite monochromators, analyzers and filters, and with fixed final energies of either 14.8 or 35 meV. Some of the higher energy transfer data were taken with a Be monochromator and a fixed final energy of 35 meV. The room-temperature results are in substantial agreement with those of Ref. 4, while the low-temperature results provide additional insight into the spin dynamics of the helical phase. Quite generally, the longitudinal scans along {100} and {110} directions give well-resolved spin-wave peaks with linear dispersion. Here we concentrate on the results along Q = (1,0,ζ) and (1,0,1+ζ) for which appreciably different spectra are observed for the two phases. This is illustrated in Fig. 1 which shows constant energy scans along (1,0,1+ζ) for the triangular phase at 295 K and for the helical phase at 100 K. Although the peaks are broad and not well resolved, these spectra indicate a single cone of dispersion centered at (101) at 295 K, and two dispersion cones centered at (1,0,1$\pm\tau$) at 100 K. These cones are shown as dashed lines in the figure. Constant-Q data are given in Fig. 2 for these two temperatures. At Q = (100), these show a pronounced anisotropy gap near 4 meV at 295 K but not at 100 K. A much broader gap-like structure appears at both temperatures near the satellite position at Q = (1,0,-0.1). The peak at 295 K is readily understood as an intersection with the quadratic dispersion surface for the triangular phase. It is more difficult to understand the origin of the peak at 100 K since an anisotropy gap is not usually expected for the helical phase. However, the spin-wave dispersion relations have not yet been derived for this lattice. Several spin-wave branches are to be expected since there are three magnetic sublattices even for the relatively simple triangular phase. This gap-like structure observed for the helical phase at 100 K may be associated with another branch which has not yet been resolved.

The results are summarized in Fig. 3 which gives the dispersion curves for both magnetic phases of Mn_3Sn. There are several features in the T = 295 K data that merit comment. First, we note that the velocity is quite high for spin waves propagating in the basal plane. Here, the spin-wave energies can be written as $(\hbar\omega)^2 = \Delta^2 + A^2q^2$ with Δ = 4.3 meV, A = 100 meV-Å for {100}, and A = 135 meV-Å for {110}. These velocities are comparable to that found in other itinerant electron systems such as MnCu and MnNi (~150 meV-Å). The anisotropy within the basal plane is unusual but probably arises from different interaction paths in these Kagomé-like hexagonal layers where some Mn atoms are replaced by non-magnetic Sn atoms. Also unusual, for an antiferromagnet, is the quadratic dispersion along {10ζ} and {11ζ} where the spin-wave energy can be described by $\hbar\omega = \Delta + 130\ q^2$ [meV]. This quadratic behavior results from the ferromagnetic coupling through the inversion center along the c axis.

The available results for the helical phase at T = 100 K are shown in the right panel of Fig. 3. If we discount the gap-like structure in the constant-Q data, then the constant-E data are well represented by linear dispersion as shown in the figure. This dramatic changeover from quadratic to linear dispersion is reminiscent of that observed in the ferromagnetic and helical phases of the rare-earth metals. [5] The dispersion is of course much steeper here, but not vertical as suggested in Ref. 4. The energy can be written as $\hbar\omega = 95\ q$ [meV], where q is now the displacement from the modulation wave vector of the helical structure.

Research supported by the Division of Materials Sciences, U.S. Department of Energy under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

References

1. S. Tomiyoshi, J. Phys. Soc. Japan 51 (1982) 803.
2. J. S. Kouvel and J. S. Kasper, Proc. Int. Conf. Magnetism, Nottingham, 1964 London (Institute of Physics) p. 169.
3. G. J. Zimmer and E. Kren, AIP Conference Proceedings No. 5 (American Institute of Physics, New York, 1972) p. 513.
4. P. Radhakrishna and S. Tomiyoshi, J. Phys.: Condensed Matter 3 (1991) 2523.
5. R. M. Nicklow, N. Wakabayashi, M. K. Wilkinson, and R. E. Reed, Phy. Rev. Lett. 26 (1971) 140.

Figure Captions

Fig. 1. Constant-E scans along Q = (1,0,1+ζ) for Mn_3Sn at T = 295 K (triangular phase) and at 100 K (helical phase). The dashed lines indicate the dispersion cones for the two magnetic phases.

Fig. 2. Constant-Q scans for the two magnetic phases of Mn_3Sn. These show a well-defined energy gap near 4 meV at 295 K and a gap-like intensity enhancement at Q = (1,0,-0.1) and T = 100 K.

Fig. 3. Dispersion curves for the two magnetic phases of Mn_3Sn. The arrow in the right panel indicates the modulation wave vector of the helical phase.

ORNL-DWG 91M-10760

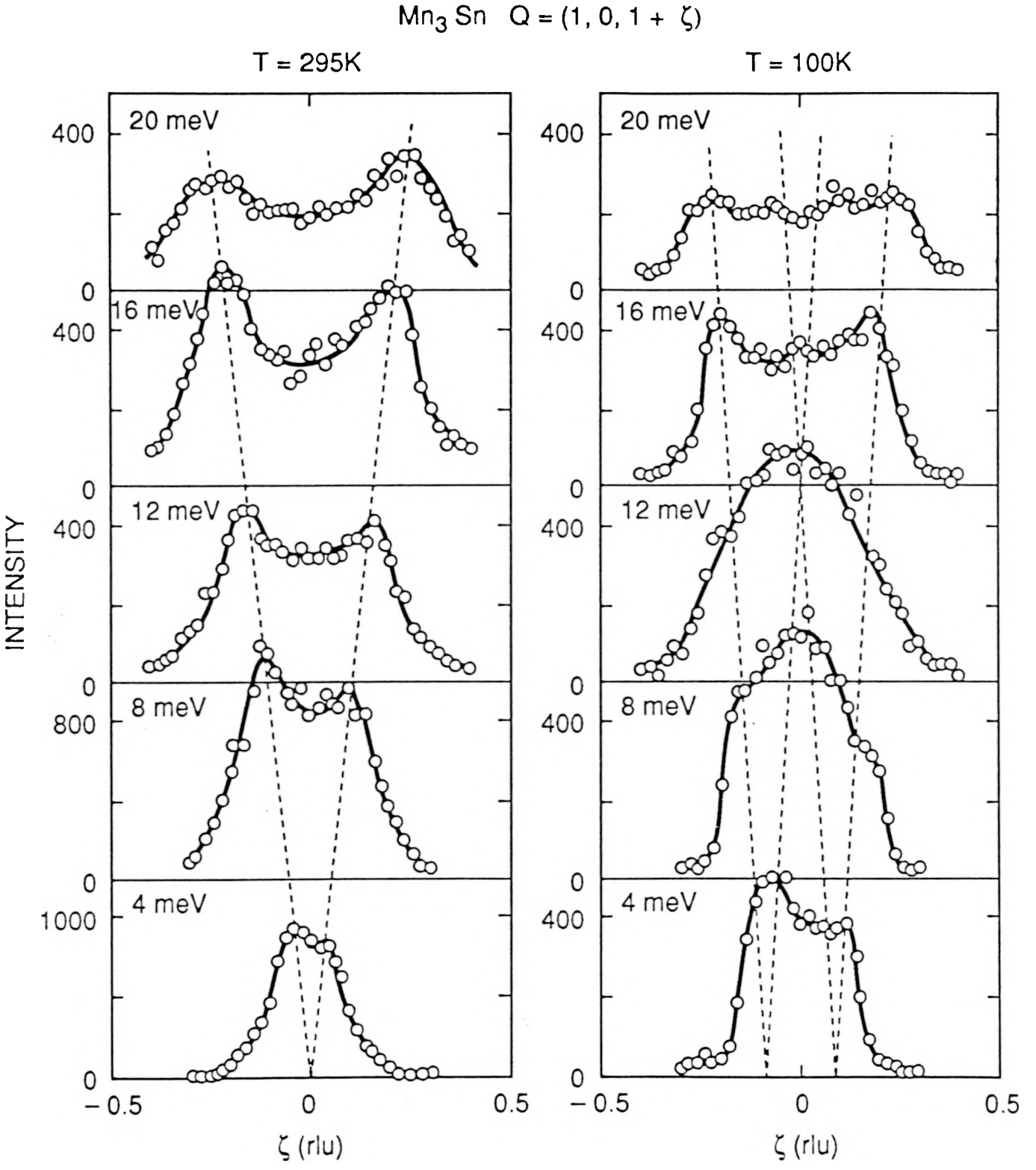

Figure 1

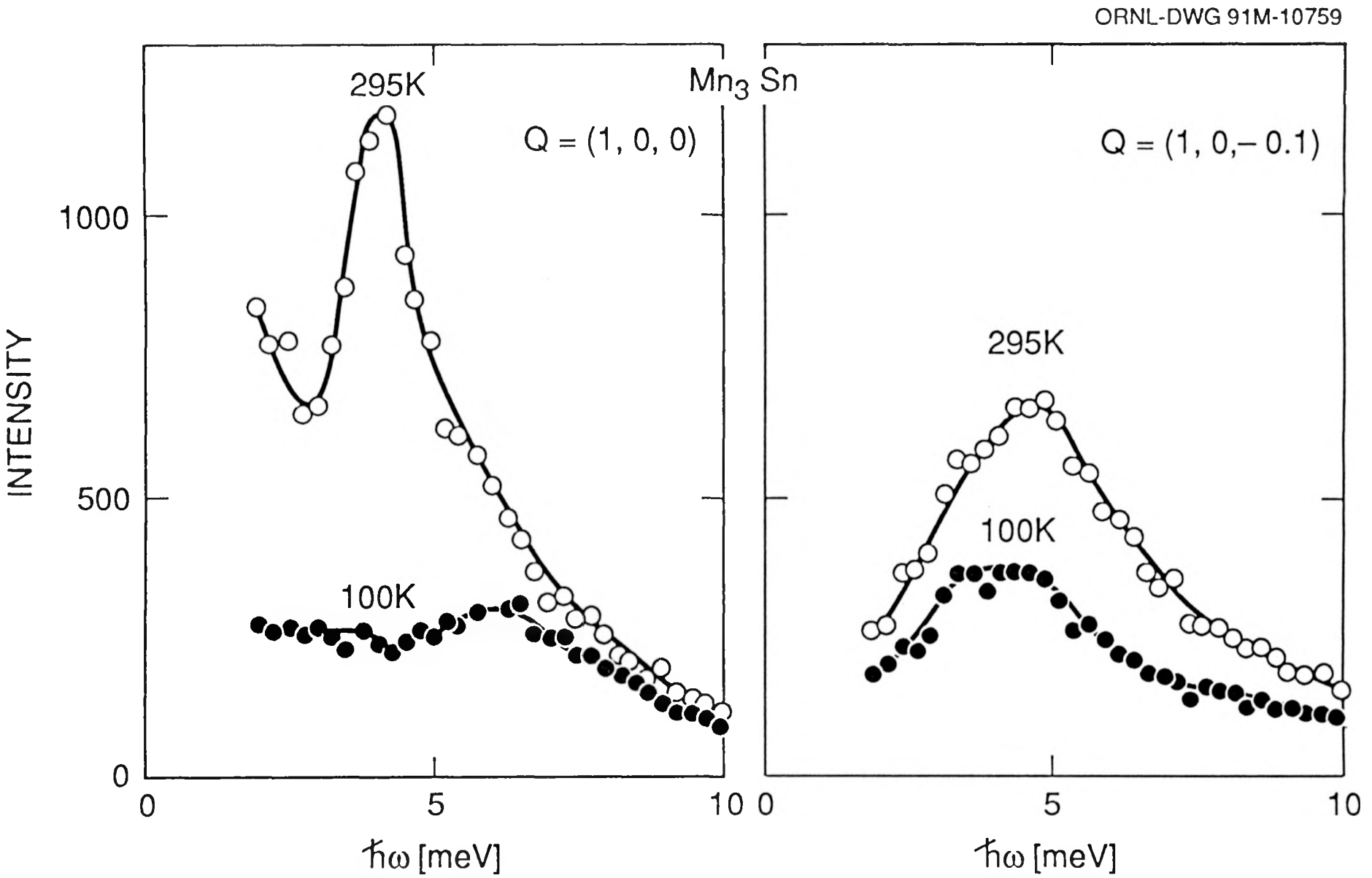
ORNL-DWG 91M-10759
Mn_3Sn
295K
Q = (1, 0, 0)
100K
295K
Q = (1, 0,– 0.1)
100K
INTENSITY
1000
500
0
0
5
10
ħω [meV]
0
5
10
ħω [meV]

Figure 2

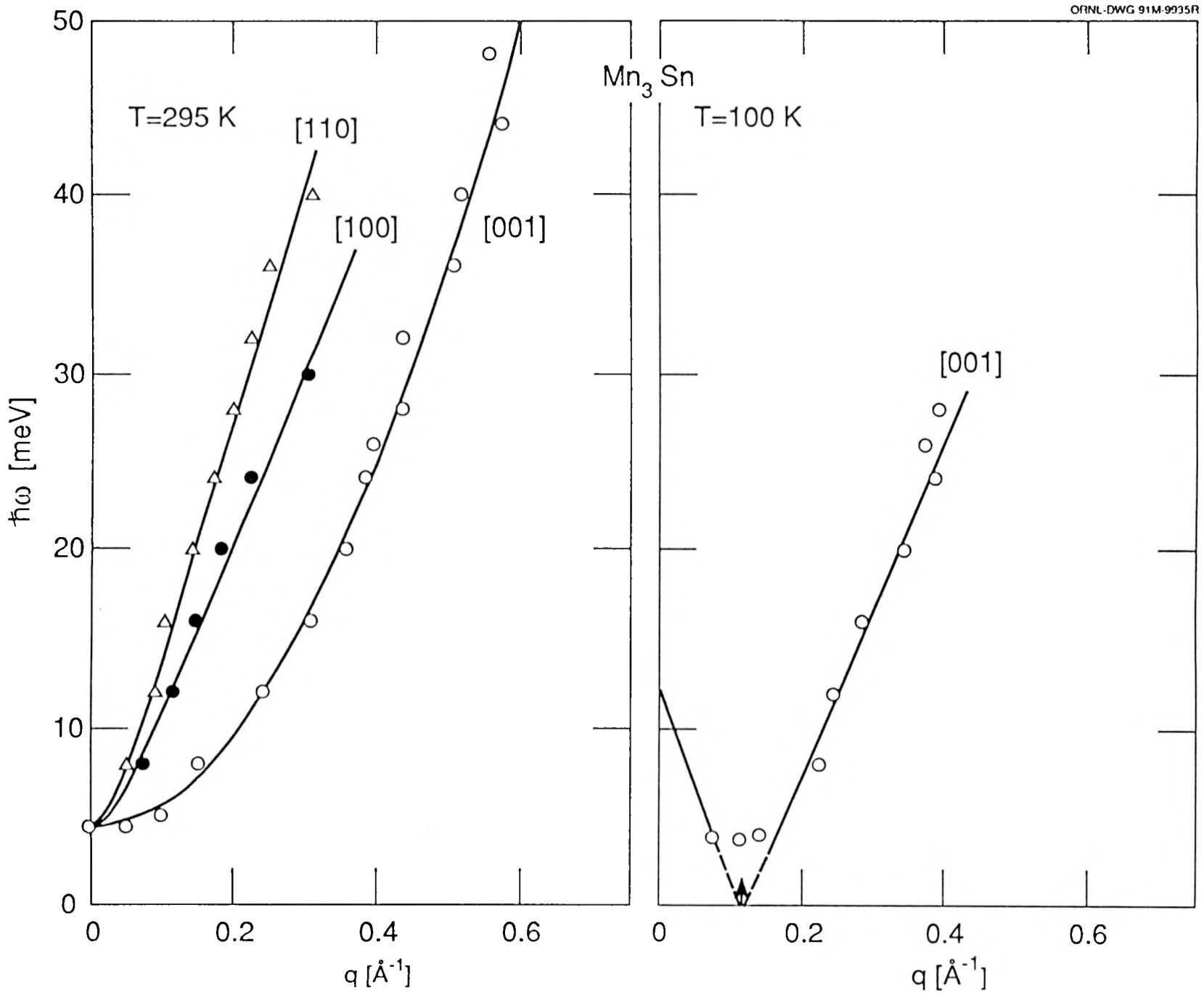
ORNL-DWG 91M-9935R
Mn_3Sn
T=295 K
T=100 K
[110]
[100]
[001]
[001]
$\hbar\omega$ [meV]
q [Å^{-1}]
q [Å^{-1}]
0
10
20
30
40
50
0
0.2
0.4
0.6
0
0.2
0.4
0.6

Figure 3