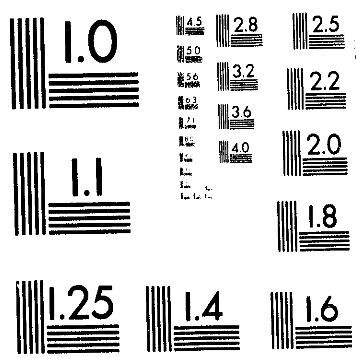
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5.0
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1.25
1.4
1.6

Conf-930865--12
BNL-49720

Incommensurate Magnetic Order in UNi_2Al_3

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Abstract

Elastic neutron scattering measurements performed on single crystal UNi_2Al_3 show this heavy fermion superconductor to display long-range incommensurate (IC) magnetic order below T_N=5.2K. The ordering wavevector is $(1/2\pm\tau,0,1/2)$ with τ=0.110±0.003, and the size of the maximum ordered moment is 0.24±0.1 μ_B/U.

Keywords: Heavy fermions, UNi_2Al_3, Incommensurate magnetic ordering, Neutron scattering

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1. Introduction

Several heavy fermion superconductors (HFS) are known to be characterized by very weak antiferromagnetically-ordered magnetic moments at low temperatures. The first two heavy fermion metals for which the existence of both antiferromagnetism and superconductivity has been established, UPt_3 [1] and URu_2Si_2 [2], display ordered magnetic moments which are of the order of $10^{-2}\mu_B/U$. More recently two new, simple hexagonal, antiferromagnetic HFS have been discovered, UX_2Al_3 (X=Pd, Ni) [3]. One of these, X=Pd, exhibits an ordered moment of almost conventional atomic size, $\mu=0.85\mu_B$. The other, UNi_2Al_3, has been known to be antiferromagnetic below ~5 K for some time, however very little detailed knowledge of its magnetically-ordered state has been obtained to date.

In this paper, we present elastic neutron scattering measurements on a single crystal sample of UNi_2Al_3 which show that this material displays an incommensurate magnetic structure below T_N~5 K. Comparison of neutron intensities of the magnetic and the nuclear Bragg peaks have enabled us to model the magnetic structure and to estimate the size of the ordered moment.

2. Experiment

The single crystal sample of UNi_2Al_3 was grown at McMaster University by Czochralski techniques, and subsequently annealed at 900°C for a week. Neutron diffraction characterization of a powder sample taken from the same boule, as well as the single crystal itself show these samples to be single phase with lattice parameters a=5.204Å and c=4.018Å at 4.2 K. The single crystal which is the subject of the study discussed below was comprised primarily of three large grains with an effective mosaic of ~1°.

Measurements were carried at the E3 triple-axis spectrometer at Chalk River Laboratories using Si(111) as monochromator and pyrolitic graphite (002) as analyzer. The collimation employed was 0.8° in both the incident and the scattered beam. The elastic scattering measurements presented here were performed mostly with neutrons of energy E'=4.12 THz and 8.23 THz. A pyrolitic graphite filter was inserted in the scattered beam at E'=8.23 THz to reduce contamination by higher order neutrons.

3. Results

An extensive search for temperature-dependent elastic scattering was performed along high symmetry directions in three different scattering planes: (h,h,l), (h,k,0), and (h,0,l). We identified such superlattice Bragg peaks only in the (h,0,l) plane, at $(1/2\pm\tau,0,1/2)$ with $\tau=0.11$. The temperature dependence of this magnetic Bragg scattering near (0.61,0,1/2) is shown in Fig. 1. As discussed below, this scattering is well described as being magnetic in origin. It rises from zero near T_N~ 5.2 K, and increases on lowering the temperature down to at least 1.5 K. This is seen in the inset to Fig. 1 which displays the peak intensity at $\Delta=0$ as a function of temperature in both warming and cooling modes. This ordering wavevector is incommensurate with the chemical lattice, and remains unchanged as a function of temperature, within the resolution of our measurements.

The relative intensities of several superlattice Bragg peaks within the (h,0,l) plane were examined in order to determine the magnetic structure. The magnetic neutron scattering cross-section is sensitive to moments lying within a plane perpendicular to **Q**, the momentum transfer of the scattering event. After accounting for the effect of the magnetic form factor of uranium, as well as the Lorentz factor in the cross section, the intensity variation within the a^*-c^* plane can be modeled as a function of the angle α between **Q** and the c-axis (see inset in Fig. 2). Fig. 2 displays this dependence as measured by neutron scattering for the following superlattice reflections: (0.39,0,1/2), (0.61,0,1/2), (1.39,0,1/2), (1.61,0,1/2), (1.61,0,3/2), (0.39,0,3/2), (0.61,0,3/2), (0.39,0,5/2). This intensity variation strongly suggests that the magnetic moments preferably lie within the hexagonal basal plane.

Several models for the magnetic structure were considered to account for these measurements. The two most successful are discussed below and predictions from these models are shown in Fig. 2. The dashed line in Fig. 2 shows the calculated α dependence for an IC antiferromagnetic structure in which spins of constant magnitude rotate within the basal plane. The solid line shows the α dependence for an IC longitudinal spin density wave (LSDW) in which the spins are polarized along the a* direction within the basal plane. Within this LSDW model, the spins vary in magnitude from site to site. The neutron intensities, corrected for all dependencies except those on α, are shown in Fig. 2 both at E'=4.12 THz and at E'=8.23 THz. As can be seen, both sets of data are consistent and clearly favor the

LSDW model with the spins polarized along a^*. This IC ordering is consistent with a recent μSR measurement [4]. Comparison of the nuclear and magnetic Bragg intensities allow us to estimate the size of the maximum ordered moment at $0.24\pm0.10\mu_B/U$ assuming that only one domain (out of three, that is that each LSDW domain is equally populated) is contributing to the scattering at any one ordering wavevector.

4. Conclusion

In summary, we have found that UNi_2Al_3 is unique among HFS in that it displays an IC antiferromagnetic phase below $T_N\sim5.2K$, characterized by an ordering wavevector $(1/2\pm\tau, 0, 1/2)$ with $\tau=0.11\pm0.003$. The variation of the magnetic Bragg peak intensity in the (h,0,l) plane is well described by the presence of a LSDW in which the magnetic moments are polarized along the a^* direction. Our measurements indicate the maximum size of the ordered moment is $0.24\pm0.10\mu_B/U$, a value consistent with previous estimates [5].

Work at McMaster University was supported by NSERC of Canada, OCMR of Ontario, and the Alfred P. Sloan Foundation. Work at Brookhaven National Laboratory was supported by the DMS of the U.S. DOE under contract DEACO276CH00016.

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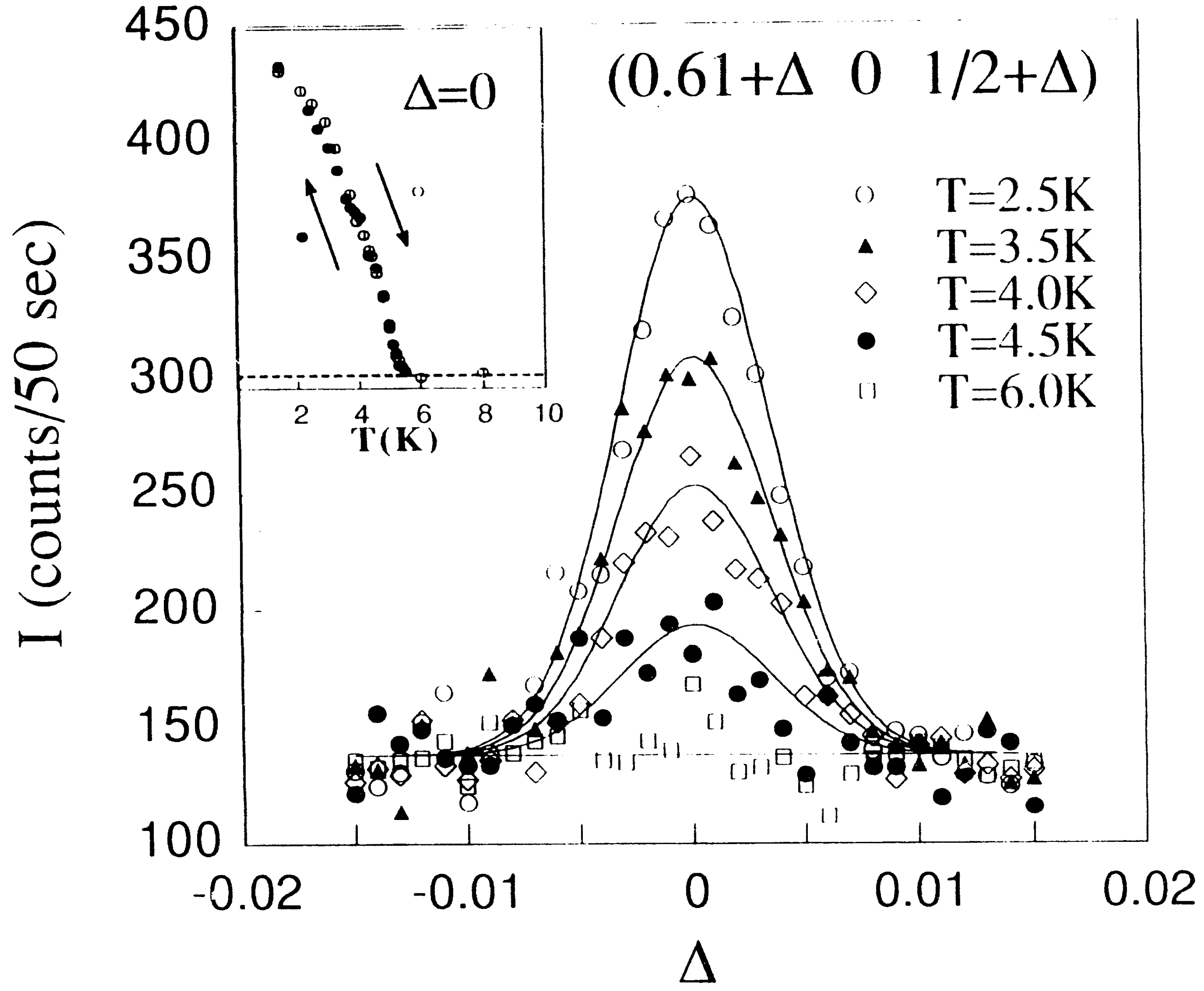
Figure captions

Fig. 1: Intensity of radial scans through (0.61,0,1/2) vs. temperature at E'=4.12 THz. Solid lines are gaussians describing the data. The inset shows the order parameter from the same set of data.

Fig.2 Magnetic intensities of several magnetic reflections I(a) vs. a (see inset). Neutron measurements were done at E'=4.12 THz (peak height: ×) and at 8.23 THz (integrated intensity: ●). The solid and dashed lines are the result of model calculations discussed in the text.



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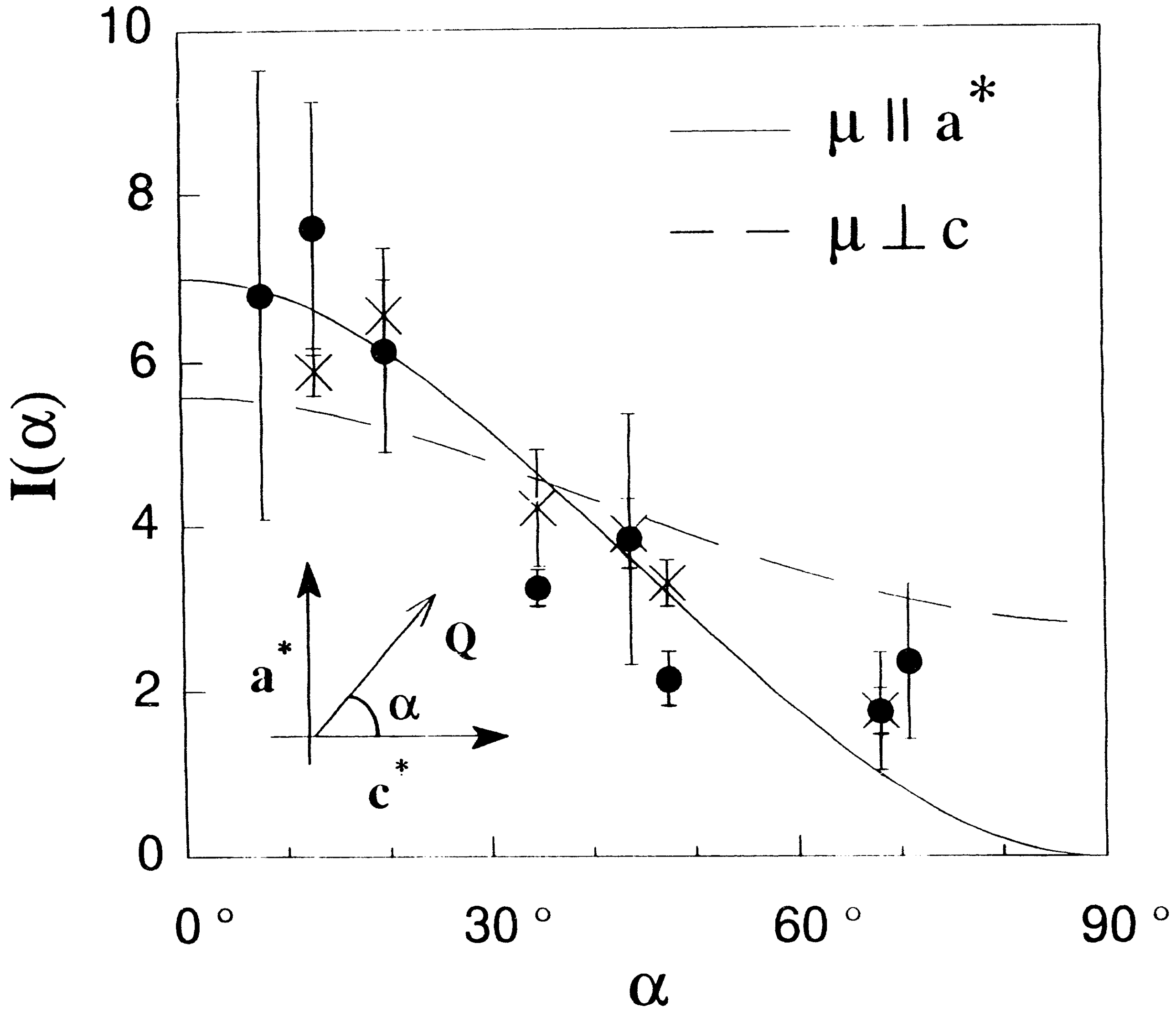
300
250
200
150
100
I (counts/50 sec)
-0.02
-0.01
0
0.01
0.02
Δ
(0.61+Δ 0 1/2+Δ)
T=2.5K
T=3.5K
T=4.0K
T=4.5K
T=6.0K
Δ=0
2
4
6
8
10
T(K)



I(α)
α
10
8
6
4
2
0
0 °
30 °
60 °
90 °
μ || a*
μ ⊥ c
a*
c*
Q
α