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Vortex lattice transitions in YNi_2B_2C

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Abstract. We have performed extensive small-angle neutron scattering (SANS) diffraction studies of the vortex lattice in single crystal YNi_2B_2C for $B \parallel c$. High-resolution SANS, combined with a field-oscillation vortex lattice preparation technique, allows us to separate Bragg scattered intensities from two orthogonal domains and accurately determine the unit cell angle, β. The data suggest that upon increasing field there is a finite transition width where both low- and high-field distorted hexagonal vortex lattice phases, mutually rotated by 45°, coexist. The smooth variation of diffracted intensity from each phase through the transition corresponds to a redistribution of populations between the two types of domains.

Keywords. (RE)Ni_2B_2C; YNi_2B_2C; vortex lattice; non-locality.

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1. Introduction

SANS [1] measurements of the mixed state in the (RE)Ni_2B_2C materials typically show the existence of a rhombic vortex lattice (VL) at low fields with its diagonal aligned with the crystallographic [110] (for $B \parallel c$). At higher fields the VL undergoes a (sharp) 45° rotation to a second rhombic phase with diagonal along the [100] axis [1,2] (at a field H_1 in [1,3]) followed by a transition to a square VL [1,2,4] (at a field H_2 [1,3]). Kogan *et al* [5] have been able to describe the vortex lattice structure, orientation and field dependence using non-local corrections to the London model. They predict a series of VL transitions characterized by a first-order 45° rotation at H_1, followed by a second-order transition to the square vortex lattice at H_2. Recently, Knigavko *et al* [6] have re-considered the analysis of Kogan *et al* by including a general description of monoclinic VL morphology in the non-local extension of the London model. They suggest that the 45° reorientation at H_1 instead occurs as two successive second-order phase transitions consisting of a gradual rotation of the unit cell accompanied by a small deformation with associated orthorhombic to monoclinic and then back to orthorhombic symmetry.

Clear evidence for a reorientation of the VL at H_1 in YNi_2B_2C was presented by Paul *et al* [1]. Due to the two-domain nature of the VL for $B \parallel c$ and resolution considerations most of these data were taken with B inclined at angles of up to 30° to the c-axis to force a single VL domain. Using the high-resolution (SANS) diffractometer D22 at the Institut Laue Langevin, Grenoble, France, combined with a field oscillation VL preparation

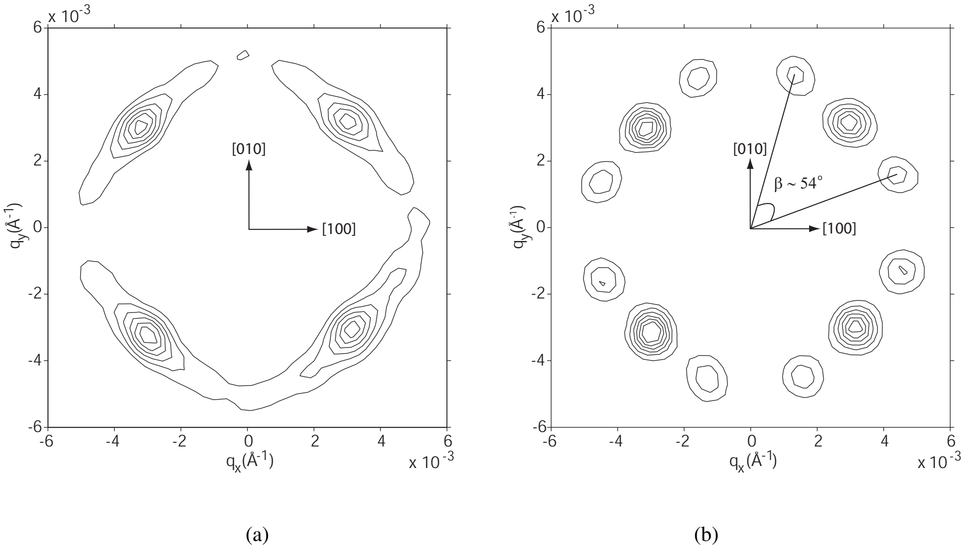

Figure 1. Vortex lattice in YNi_2B_2C at 100 mT. (**a**) Field cooled (FC) and (**b**) field cooled + wiggle (FCW) at 2 K.

technique, we have been able to successfully resolve Bragg reflections from each VL domain for $B\|c$. The nature of the 45° reorientation at H_1 has been re-examined in an attempt to confirm or refute the current theoretical prediction.

2. Results and discussion

Figure 1a shows diffraction from the VL 'grown' by field cooling (FC) to 2 K in an applied field of 100 mT (i.e. below H_1). The FC method in principle results in an internal field distribution close to that of the equilibrium magnetization. On the other hand, competition between Meissner expulsion and pinning during FC often results in a disordered VL with smearing of the scattered intensity between the Bragg reflections, as shown in figure 1a. We have found previously [7] that FC followed by a 10% damped sinusoidal modulation ('wiggle') about the applied field (FCW) often results in a more perfect VL structure. Figure 1b shows the same VL as in figure 1a after a 10% oscillation about the applied field. The difference in quality of the VL after the FCW procedure is significant, enabling diffracted peaks from both domains of the low-field rhombic VL to be clearly resolved. For the VL shown in figure 1b the unit cell angle, β, is around 54° with diagonal aligned with the [110].

Figure 2 shows the FCW VL at 2 K, in an applied field of 150 mT, close to the 45° reorientation transition region at H_1. The key feature of our argument is that we observe contributions from 4 domains of VL, two aligned as in figure 1b with diagonal along the [110] and two rotated by 45° with diagonal along the [100]. This is most clearly apparent by the appearance of scattering at positions that can only be indexed as higher order reflections from either the low- and high-field phases below and above H_1 respectively, as indicated

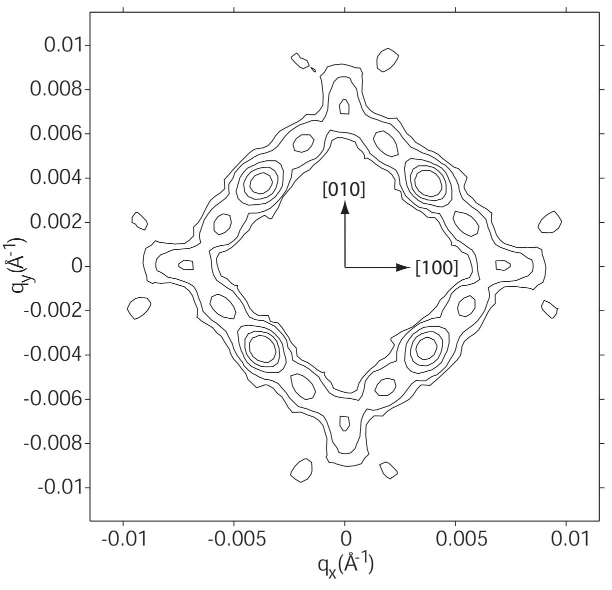

Figure 2. Vortex lattice (FCW) at 150 mT and 2 K. Higher-order Bragg diffraction peaks from the VL show a coexistence of the low- and high-field distorted rhombic phases.

on the figure. Furthermore, the unit cell angle, β, for both orientations of VL shows no sign of continuous distortion through H_1. As the applied field is increased above H_1 the intensity from the high-field VL phase rapidly increases as that from the low-field phase decreases. We believe the transition through H_1 is best described as a first-order transition with coexistence of both phases over a narrow field range ($\sim$ 30 mT). The population of each phase varies as the phase boundary progresses through the macroscopic crystal.

The higher field, rotated two-domain phase is shown more clearly in figure 3 at 170 mT, just above H_1. Here data is presented at 10 K where the splitting of the two domains is more apparent (H_1 itself is approximately temperature independent). Here there is no evidence of the low-field phase and β opens away from a hexagonal towards a square VL. As the applied field is increased yet further, β smoothly opens out and eventually reaches 90° as shown in figure 4. The diffraction peaks from the two orthogonal, square domains are now coincident. This is most noticeable in the second-order peaks which now have almost isotropic widths.

3. Conclusion

In conclusion, our high-resolution SANS measurements support the notion of a first-order reorientation transition from a state with the diagonal of the rhombic unit cell along a [110] to a [100] direction at H_1. We find no evidence for a continuous distortion of the vortex lattice between the two states. Rather, a smooth variation in scattered intensity corresponds to

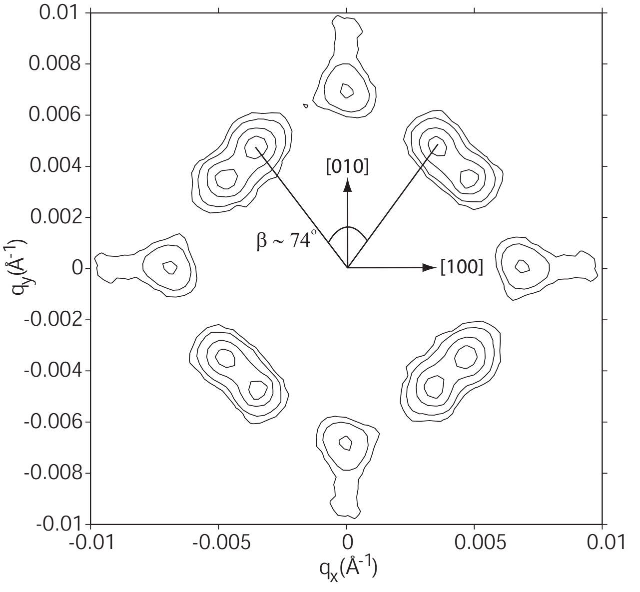

Figure 3. Vortex lattice (FCW) at 170 mT. Splitting of the two domains of distorted rhombic VL is best illustrated at higher temperatures, shown here at 10 K.

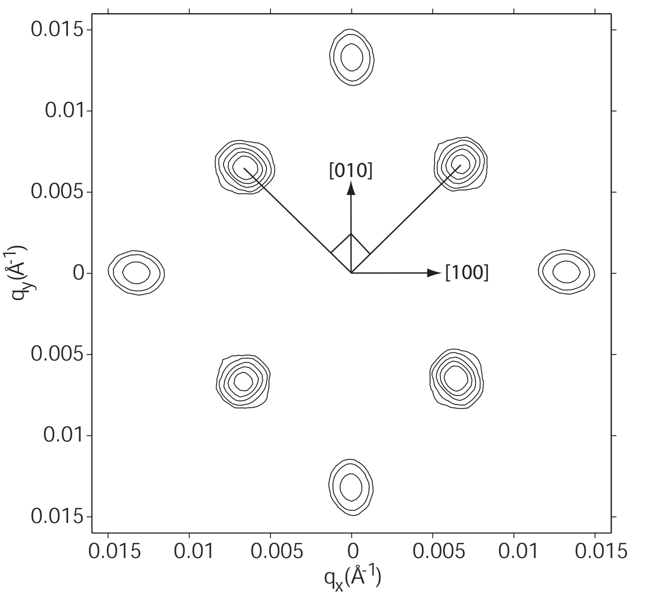

Figure 4. Square vortex lattice (FCW) at 450 mT and 2 K.

a redistribution of populations between the two types of unit cells. The continuous manner in which the high-field unit cell distorts from rhombic to square geometry is consistent with the proposed second-order phase transition at H_2.

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