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Flux line lattice symmetries in the borocarbide superconductor $LuNi_2B_2C$

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Abstract. We compare the results of small angle neutron scattering on the flux line lattice (FLL) obtained in the borocarbide superconductor $LuNi_2B_2C$ with the applied field along the *c*- and *a*-axes. For $\mathbf{H} \parallel \mathbf{c}$ the temperature dependence of the FLL structural phase transition from square to hexagonal symmetry was investigated. Above 10 K the transition onset field, $H_2(T)$, rises sharply, bending away from $H_{c2}(T)$ in contradiction to theoretical predictions of the two merging. For $\mathbf{H} \parallel \mathbf{a}$ a first order FLL reorientation transition is observed at $H_{\mathrm{tr}} = 3$–3.5 kOe. Below H_{tr} the FLL nearest neighbor direction is parallel to the *b*-axis, and above H_{tr} to the *c*-axis. This transition cannot be explained using nonlocal corrections to the London model.

Keywords. Borocarbide; flux line lattice; symmetry.

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1. Introduction

Over the last couple of years, the flux line lattice (FLL) in borocarbide superconductors [1] have been under intense scrutiny. In these materials, the nonlocal flux line interactions [2] are large enough to stabilize a square FLL [3] but only with a small margin. A small reduction of the nonlocal electrodynamics by increasing the flux line spacing [4], reducing the mean free path [5] or raising the temperature [6] is enough to drive the FLL into a transition towards a hexagonal symmetry expected for an isotropic superconductor.

2. Experimental

The borocarbides, which are quaternary intermetallics with stoichiometry RNi_2B_2C ($R = $ Y, Gd–Lu) and a tetragonal unit cell [1], have attracted attention due to the coexistence of superconductivity ($R = $ Y, Dy–Tm, Lu) and antiferromagnetic ordering

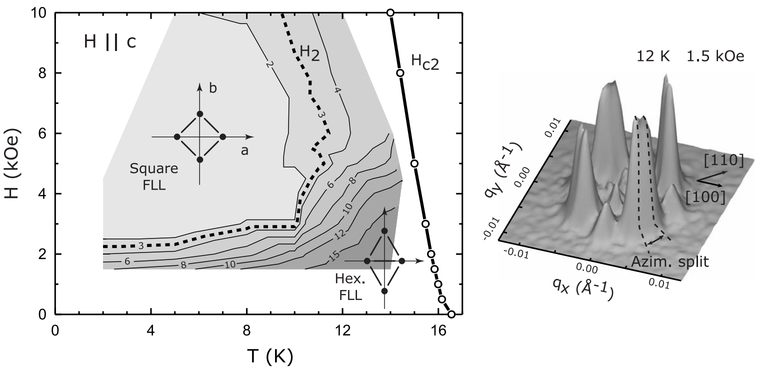

Figure 1. Left: (H, T)-phase diagram showing constant azimuthal splitting contours. The dashed line (3° splitting) is taken as $H_2(T)$. The shaded area indicates the range of our measurements. **Right:** SANS FLL diffraction pattern showing the splitting of the (1, 0) peaks.

($R =$ Gd–Tm). They are strong type-II superconductors with Ginzburg–Landau parameter, $\kappa = 6$–15.

The FLL symmetry in nonmagnetic $LuNi_2B_2C$ ($T_c = 16.6$ K) was studied using the small angle neutron scattering (SANS) spectrometer at the Risø National Laboratory DR3 research reactor, for two different magnetic field directions, along the c-axis and along the a-axis. Details of the experiments are published elsewhere [6,7]. In both cases background data obtained above T_c following a zero field cooling was subtracted.

3. H‖c

For this field orientation, the onset of the square to hexagonal transition, $H_2(T)$, was measured up to 1 tesla [7]. The harbinger of the transition is the azimuthal splitting of the FLL (1,0) reflections [4] as shown in figure 1 (right). By mapping the magnitude of the splitting in a contour plot, we obtain the phase diagram in figure 1 (left).

Below 10 K, $H_2(T)$ is only weakly temperature dependent, but for $T > 10$ K, it rises sharply, bending away from $H_{c2}(T)$ in contradiction to theoretical predictions of $H_2(T)$ merging with $H_{c2}(T)$ [8]. This suggests that just below the $H_{c2}(T)$ curve the FLL might be hexagonal, probably because the FLL elastic modulii soften due to fluctuations when $H_{c2}(T)$ is approached [9].

4. H‖a

For this geometry, calculations based on a nonlocal generalization of the London model which have been successfully applied for $\mathbf{H}\|\mathbf{c}$, predict a similar 'square to hexagonal' transition except that the FLL should be distorted due to the effective mass anisotropy in the ac-plane [2,6]. However, as shown in figure 2, the situation is quite different.

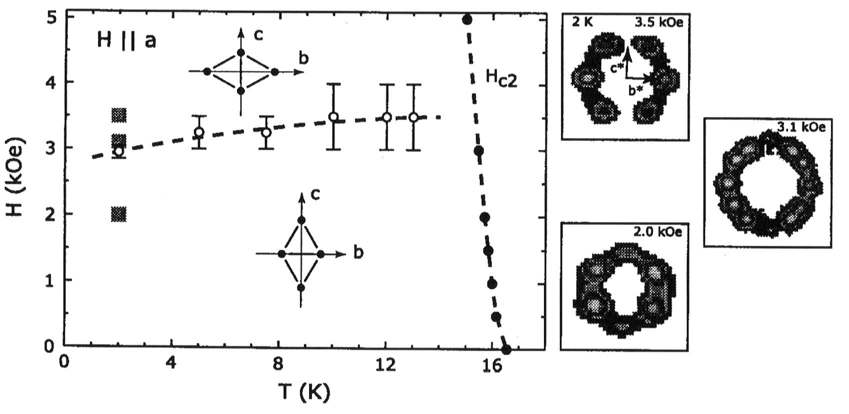

Figure 2. Phase diagram showing the FLL reorientation transition field, H_{tr}, and the upper critical field, $H_{c2}(T)$. The error bars represent the precision to which H_{tr} was determined. Shown right, are diffraction patterns for the positions marked by the shaded squares. Note how these are rotated 90° with respect to the direct space FLL orientation shown in the phase diagram.

For this geometry, the FLL assumes a distorted hexagonal symmetry throughout the phase diagram, but undergoes a 90° reorientation transition at $H_{tr} = 3$–3.5 kOe [6]. Furthermore, only a minor temperature dependence is observed.

5. Summary

In this article we have shown the two rather different FLL phase diagrams for $LuNi_2B_2C$ obtained when the applied field is along the c- or a-axis. This difference is quite intriguing as there is a good theoretical understanding for the $\mathbf{H}\|\mathbf{c}$ behavior. However, it is unclear what makes the case of $\mathbf{H}\|\mathbf{a}$ fundamentally different.

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