

Flux line lattice symmetries in the borocarbide superconductor $\text{LuNi}_2\text{B}_2\text{C}$

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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 $\text{LuNi}_2\text{B}_2\text{C}$ with the applied field along the c - and a -axes. For $\mathbf{H} \parallel c$ 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 $\mathbf{H} \parallel a$ a first order FLL reorientation transition is observed at $H_{tr} = 3\text{--}3.5$ 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 borocarbitides, which are quaternary intermetallics with stoichiometry $R\text{Ni}_2\text{B}_2\text{C}$ ($R = \text{Y}, \text{Gd-Lu}$) and a tetragonal unit cell [1], have attracted attention due to the coexistence of superconductivity ($R = \text{Y}, \text{Dy-Tm}, \text{Lu}$) and antiferromagnetic ordering

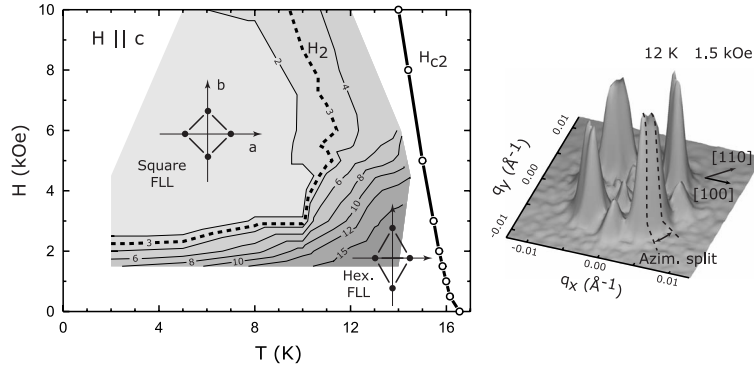


Figure 1. Left: (H, T) -phase diagram showing constant azimuthal splitting contours. The dashed line (3° splitting) is taken as $H_2(T)$. The shaded area indicates the range of our measurements. **Right:** SANS FLL diffraction pattern showing the splitting of the $(1, 0)$ peaks.

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

The FLL symmetry in nonmagnetic $\text{LuNi}_2\text{B}_2\text{C}$ ($T_c = 16.6\text{ K}$) 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. $\mathbf{H}\parallel\mathbf{c}$

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 $T > 10\text{ K}$, 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 moduli soften due to fluctuations when $H_{c2}(T)$ is approached [9].

4. $\mathbf{H}\parallel\mathbf{a}$

For this geometry, calculations based on a nonlocal generalization of the London model which have been successfully applied for $\mathbf{H}\parallel\mathbf{c}$, 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.

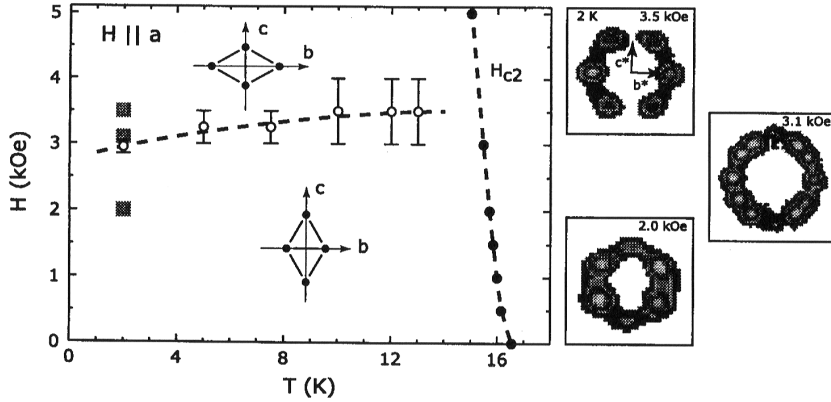


Figure 2. Phase diagram showing the FLL reorientation transition field, H_{tr} , and the upper critical field, $H_{c2}(T)$. The error bars represent the precision to which H_{tr} was determined. Shown right, are diffraction patterns for the positions marked by the shaded squares. Note how these are rotated 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 $H_{tr} = 3\text{--}3.5$ 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 $\text{LuNi}_2\text{B}_2\text{C}$ 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 $\mathbf{H}\parallel c$ behavior. However, it is unclear what makes the case of $\mathbf{H}\parallel a$ fundamentally different.

References

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