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INFLUENCE OF MAGNETISM ON FLUX LINE LATTICE IN $TmNi_2B_2C$ SUPERCONDUCTOR

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We have examined the phase boundary of the square flux line lattice in $TmNi_2B_2C$ using small angle neutron scattering and the transition into a rhombic lattice for $H > 2$ kOe is found to scale with the upper critical field $H_{c2}(T)$ of the superconductor. The influence of the magnetic Tm-ions on the flux line lattice symmetry in the paramagnetic state seems only indirect through the shape of the upper critical field.

A co-existence of superconductivity and magnetic ordering of the rare earth moment in the form of a spin-density wave (SDW) is observed in the borocarbide series $R\text{Ni}_2\text{B}_2\text{C}$, when the rare earth is R = Tm, Er, Ho or Dy. The presence of the rare earth moments polarises the conduction electrons, which mediates the indirect RKKY interaction between different moments. However, the superconducting state is also formed by the conduction electrons and a strong interplay between magnetism and superconductivity is seen. In the case of R = Tm a quite complicated phase-diagram of the flux line lattice symmetries is found when the applied field is oriented along the c-axis of the tetragonal crystalline unit cell[1], as shown on Fig 1. The critical temperature is $T_c = 11$ K and the maximum upper critical field $H_{c2} = 10$ kOe is found at $T = 5$ K. At lower temperatures H_{C2} shows a minimum as the magnetic ordering of the q_{mI} and q_{mII} SDW is setting in at $T_N = 1.5$ K. In the paramagnetic phase $T_N < T < T_c$ a smooth transition from a rhombic to a square flux line lattice is seen as the applied field in increased from the lower critical field H_{c1}. This transition is driven by non-local electrodynamics, which favours a four-fold symmetric current and field pattern, depending on the underlying Fermi surface symmetry, when the field profile of the flux lines is highly overlapping[2]. Insert D and A illustrates the change from an almost hexagonal to a square flux line lattice, which is common for even the non-magnetic borocarbides R = Y and Lu.[3] A transition back into a rhombic symmetry is observed as the applied field is increased towards the upper critical field H_{c2}. Small angle neutron scattering (SANS) has been used to measure the azimuthal width of the diffraction spots from the square flux line lattice. The transition field H_{c2} between the A and B phase was determined as the field, where the width increased above the resolution of the SANS camera and insert B shows two rhombic lattices clearly resolved.

It has been argued that the square flux line lattice would not exist close to H_{c2}, because the separation between the flux lines is larger for the rhombic than the square lattice, whereby the loss of condensation energy is smaller when the superconducting order parameter is suppressed in between the flux lines as the vortex cores start to overlap.[3] Thus the AB phase transition is expected to coincide with the crossover from intermediate to high flux line density, which is often defined by the field where the flux line separation a is a factor $C_{\mathrm{IH}} \approx 4$ larger than the superconducting coherence length ξ.[4] Flux quantization for the square flux line lattice gives a relation between magnetic flux density B and the separation between the flux lines

$$\Phi_0 = B\,a^2$$

The coherence length ξ is connected to the upper critical field B_{C2} by inserting $a = \sqrt{2\pi}\xi$, whereby it is seen that the AB phase transition scales with the upper critical field by

$$\frac{B_{\mathrm{AB}}}{B_{\mathrm{C2}}} = \frac{2\pi}{C_{\mathrm{IH}}^2}$$

From the AB phase boundary of figure 1 one gets an estimate of C_{IH} = 3.96-3.45, which is in qualitative agreement with the definition of the crossover from intermediate to high flux line density.

It is suggested that the square flux line lattice exist between a lower phase boundary (AD) determined by non-local electrodynamics and an upper boundary (AB), where the vortex cores start to overlap. Thus the influence of the magnetic Tm-ions on the flux line lattice symmetry seems only to be indirect through the shape of the upper critical field $H_{c2}(T)$ curve in the paramagnetic phase.

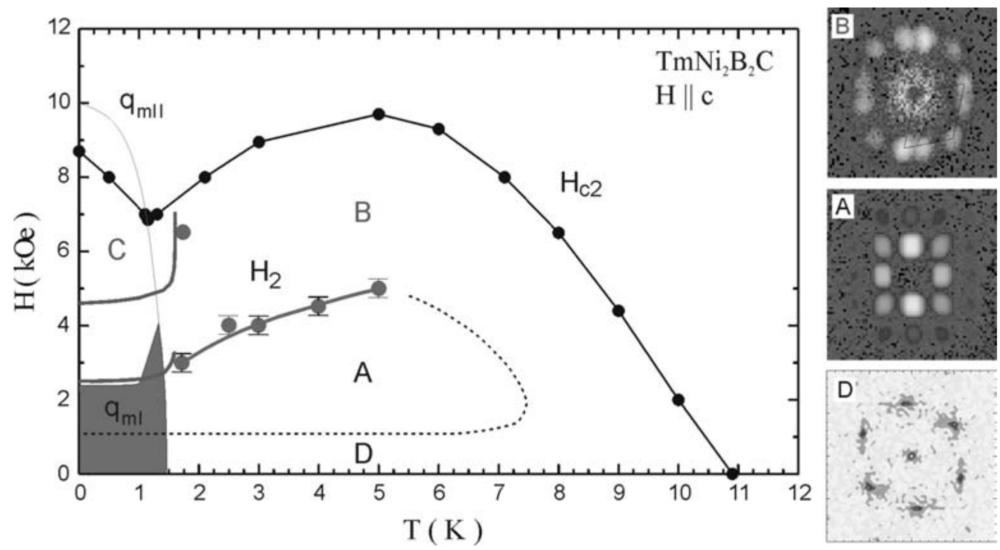

Fig. 1. Phase diagram of $TmNi_2B_2C$ showing square (A) and different rhombic flux line lattices (B, C, D). It is suggested that the AB phase boundary has a positive slope, because it scales with the upper critical field H_{c2}. Insert D: Magnetic decoration showing rhombic lattice at H = 20 Oe and T = 4.2 K, A: Square lattice at H = 2.0 kOe and T = 2.3 K, B: Rhombic lattice at H = 6.5 kOe and T = 1.7 K.

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