VORTEX LATTICE STUDIES IN NOVEL SUPERCONDUCTORS USING SMALL ANGLE NEUTRON SCATTERING

Abstract

by

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$CeCoIn_5$ is a heavy fermion superconductor with a highest known T_c of 2.3 K. Vortex lattice (VL) studies using Small Angle Neutron Scattering (SANS) have shown a rich VL phase diagram with $\mathbf{H} \parallel [\mathbf{0\ 0\ 1}]$. At low and intermediate fields, one sees a VL transition from hexagonal to rhombic to square symmetry. The transition can be explained on the basis of anisotropy effects and non-local corrections to the London model. As the applied field is increased, a reverse sequence of transition from square to rhombic to hexagonal symmetry is observed which shows that the four-fold anisotropy that stabilized the square phase is gradually reduced.

The VL form factor which is a measure of the field contrast in the mixed state, shows an unconventional behavior with $\mathbf{H} \parallel [\mathbf{0\ 0\ 1}]$. Instead of an exponential decay as expected from a conventional superconductor, the form factor increases with the increase in the applied field and drops off just before entering the normal state. At low temperatures, our results show that competition between the parallel alignment of electron spins in the vortex cores and the antiparallel alignment demanded by d-wave pairing give rise to magnetized cores, which give the increase in form factor with H (Pauli paramagnetic effects). However, the form factor

falls near the upper critical field; the fall-off extends outside the proposed Fulde-Ferrell-Larkin-Occhinnikov (FFLO) phase region and is believed to arise from the expansion of the magnetized cores. At higher temperatures, we observe a gradual crossover towards more conventional mixed state behavior.

When the field is applied along the basal plane of the crystal, a single VL orientation is observed for $\mathbf{H} \parallel [\mathbf{1\ 0\ 0}]$, while a 90° reorientation transition is found for $\mathbf{H} \parallel [\mathbf{1\ 1\ 0}]$. For both field orientations and VL configurations we find a distorted hexagonal VL with an anisotropy, $\Gamma = 2.0 \pm 0.05$. The VL form factor shows strong Pauli paramagnetic effects similar to what have previously been reported for $\mathbf{H} \parallel [\mathbf{0\ 0\ 1}]$. At high fields, above which the upper critical field (H_{c2}) becomes a first-order transition, an increased disordering of the VL is observed.

The superconductor $TmNi_2B_2C$ possesses a significant four-fold basal plane anisotropy leading to a square Vortex Lattice (VL) at intermediate fields. However, unlike other members of the borocarbide superconductors, the anisotropy in $TmNi_2B_2C$ appears to decrease with increasing field evident by the VL transition from square to rhombic to hexagonal symmetry, similar to what was observed in $CeCoIn_5$. We have used Small Angle Neutron Scattering measurements of the VL to study the field dependence of the anisotropy. Our results provide a direct, quantitative measurement of the decreasing anisotropy. We attribute this reduction of the basal plane anisotropy to the strong Pauli paramagnetic effects observed in $TmNi_2B_2C$ and a resulting expansion of vortex cores near H_{c2}.