ASPECTS OF VORTEX PHYSICS IN $CeCoIn_5$

Abstract

by

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$CeCoIn_5$ is a heavy-fermion superconductor (HFS) with a plethora of interesting phenomenon such as the highest critical temperatures for a HFS and the presence of a quantum critical point(QCP) brought on by changing an applied magnetic field or pressure to the sample. Along with $CeCoIn_5$, $TmNi_2B_2C$ was investigated which is interesting because it orders antiferromagnetically at temperatures below $T_{\mathrm{N}} = 1.5$ K and a superconducting critical temperature, $T_c = 11$ K. It also possess a strong paramagnetic phase that extends into the superconducting state from the normal. Normally, superconductivity and magnetism are considered to be mutual exclusive but in $TmNi_2B_2C$ they are both present which makes this a unique compound. Using small angle neutron scattering (SANS) as a probe of the vortex lattice (VL), both samples were investigated. The focuses of the studies were: the VL structure in $CeCoIn_5$ and the VL form factor in $TmNi_2B_2C$ and $CeCoIn_5$.

The VL symmetry in $CeCoIn_5$ transitions from a low field hexagonal symmetry to a distorted rhombic and to a square. As the field is increased, the VL transitions back to the distorted rhombic symmetry and at fields close to H_{c2}, it transitions back to hexagonal. The low field transitions are believed to be due to one of two types of anisotrophies (i) Fermi surface anisotropy/non-local electrodynamics and (ii) $d-$wave nature of the pairing symmetry. For the higher field symmetry transition

it is believed to be due to a weakening in the fourfold anisotropies. This is caused by the fact that the field at the center of the vortex must display cylindrical symmetry as it does at low fields. This effect is most likely amplified by the Pauli limiting process that becomes more important as one approaches H_{c2}.

The form factor, which is the Fourier transform of the magnetic field in the vortex core, usually falls off monotonically as a function of field. $TmNi_2B_2C$'s form factor remains constant until $0.6H_{c2}$ where it begins decrease. Ichoika and Mashida used a simple model to describe the H and T dependencies, the model was able to capture the qualitative and quantitative behavior of the form factor, emphasizing that paramagnetic effects are important to understanding the vortex state in $TmNi_2B_2C$. The model is based the conduction electron paramagnetic moments induced by the exchange interaction with the $4f$ Tm moments accumulate exclusively around the vortex cores, creating nanotubes of Tm magnetization and maintains the field distribution contrast in VL.

In contrast, $CeCoIn_5$'s form factor remains constant at low fields but rapidly starts to increase as the field is increased. This can partially be attributed to the paramagnetic effect but since $CeCoIn_5$ is Pauli-limited therefore is expected that the parallel spin alignment of the quasi-particles in the core is greater thus giving an increase in the form factor. Another possible explanation for this increase is due to the presence of a QCP when one approaches H_{c2}. There is also an abrupt drop off in the form factor. This drop occurs in the same region of the phase diagram that the proposed Fulde-Farrel-Larkin-Ovchinnikov (FFLO) state inhabits.