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Going to Extraordinary Lengths in Superconducting Vortex Matter

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In the superconductor niobium the vortex-vortex interaction exhibits in addition to the purely repulsive also an attractive term. This leads to the formation of the intermediate mixed state (IMS) where flux-free Meissner state domains and mixed state domains filled with vortex lattice coexist separated on the micrometer length scale. Besides being a prominent example of exotic vortex matter this two-phase structure can also act as a highly tunable model system for universal domain physics as both the intervortex distance and the domain structure can be tuned via the magnetic field and temperature [1].
Small angle neutron scattering (SANS) is the ideal tool to study the Bragg peaks from the vortex lattice with inter-vortex distances of 100-200 nm. Given the rough upper limit in SANS of 1 micrometer it struggles to capture the diffuse scattering from the domain boundaries with sizes of up to 50 micrometers. However, the power-law tail of the diffuse scattering extends into the SANS regime and contains valuable information about the domain structure. Conventionally, the power-law of diffuse scattering is analyzed using the Porod law connecting the scattering intensity to the specific surface area of randomly distributed scattering particles [2]. We show that in the specific case of the IMS, where the domain boundaries are close to parallel to the direct beam, the specific surface area can be interpreted as an inverse length corresponding to the size of the domain structure [3]. Using this approach, that takes into account the alignment of the domain boundaries along the beam direction to extract the correct specific surface area, we are able to extend the accessible length scales from 1 micrometer to up to 40 micrometers using a standard SANS setup.
Our results fit well with Landau's theory of superconducting domains [4], previous attempts of extracting this length scale using ultra small angle neutron scattering [5] and highlight the power of our approach of extending the accessible length in SANS to the micrometer regime. Our analysis approach should be applicable to other two-phase systems where the domain boundaries are close to parallel to the incoming neutron beam.
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