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LE-muSR Study of the Field Distribution and the Domain Shape near the Surface of Superconductors in the Intermediate State*

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As known (Landau, 1937), the equilibrium domain structure of the magnetic flux in type-I superconductors in the intermediate state is formed due to the competition between the energy contributions to the sample free energy arising from the superconducting/normal interfaces, on one side, and the contributions due to an inhomogeneous field distribution and the domains shape (FDDS) near the sample surface, on the other. Landau suggested two scenarios for FDDS, other scenarios were proposed by Tinkham, Marchenko and Abrikosov. However, none of these scenarios meets the fundamentals of the Laplace-based magnetostatics being simultaneously consistent with observed flux structure. We will report on for the first time performed direct measurements of the FDDS near the surface of planar samples in the intermedium state, i.e., on high purity indium films in a normally applied field. The measurements were carried out using LE-μSR. The range of the probed distances from the surface extends from 0.1 μm inside to 1 μm outside the sample. It was found that, contrarily to what follows from the Laplace equation, the current-free space outside the samples contains voids extending over a large-scale distance, which can exceed the thickness of the samples. More specifically, at low fields the measured FDDS is close to that suggested by Tinkham. However, at high fields the real FDDS differs from all predictions: the width of the superconducting domains widens instead of expected narrowing and outside the samples the field passes through a maximum, in apparent violation of Earnshaw's theorem. It will be shown that the observed FDDS is thermodynamically the most favorable for the superconducting sample, which leads to inapplicability of the Laplace equation and, consequently, the Earnshaw theorem in a wide vicinity of the sample in the intermediate state.

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Primary authors: Prof. KOZHEVNIKOV, vladimir; Dr SUTER, Andreas (PSI); Dr PROKSCHA, Thomas (PSI); Prof. VAN HAESENDONCK, Chris (KU Leuven)

Presenter: Prof. KOZHEVNIKOV, vladimir

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