Equilibrium magnetization of superconductors: beyond simple London theory

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The equilibrium magnetization M_{eq} offers a useful way to probe the vortex system in Type II superconductors. In general, simple London theory, which assumes a local proportionality between the supercurrent density **j** and vector potential **a**, captures much essential physics without requiring detailed microscopic properties of the superconductor. It gives an isotropic repulsion between vortices and predicts a logarithmic field dependence for M_{eq}, with $M_{eq} \propto -(\phi_0/\lambda^2)\times\ln(\beta H_{c2}/B)$, for flux densities B well removed from the lower and upper critical fields, i.e., $H_{c1} << B << H_{c2}$. This formalism has been very useful in investigating both conventional and high-T_c superconductors, as it gives access to two length scales, the London penetration depth λ and the coherence length ξ through H_{c2}. It is expected to fail, however, when its basic assumptions are violated.

We have investigated two classes of materials that go beyond simple London theory. In one case, we change the energetics by adding *randomly oriented columnar defects* (fission ion tracks) that tend to pin the vortices. The added pins progressively modify the simple logarithmic field dependence and significantly reduce the magnitude of M_{eq}. The experimental results are described reasonably well, however, by theory from Wahl and Buzdin that adds pinning effects to the system energy. In the second case with very clean materials, **j** and **a** are related by *nonlocal electrodynamics*, which again modifies the simple relation between the equilibrium magnetization and magnetic field. Indeed, extensive experimental studies in single crystal YNi_2B_2C reveal significantly modifications of $M_{eq}(H,T)$. We find that the Kogan-Gurevich extension of London theory, modified to include nonlocal effects, provides a quite good and internally consistent description of the experiments. The same nonlocality leads to structural transformations in the vortex lattice, which have been observed by others using small angle neutron scattering and scanning tunneling microscopy. Further details of the magnetization studies will be reported.

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