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d-wave quasiparticles and the origin of vortex viscosity in cuprates

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The frictional force experienced by a quantized flux line moving in a conventional superconductor arises primarily from induced vortex electric fields coupling to charge excitations within the vortex core. This was first captured by Bardeen-Stephen theory, which treats the vortex core as a tube of normal metal embedded in a superconducting background. The theory is applicable to conventional superconductors for two reasons: the vortex cores are large and contain a nearly continuous spectrum of single-particle states; and s-wave pairing symmetry results in a low density of extended states surrounding the vortex core. In cuprate superconductors the opposite situation holds: small vortex cores contain at most a few discrete states, with a continuum of low lying states outside the vortex core due to the nodes in the d-wave energy gap.

To explore these differences, microwave techniques have been used to probe the frequency dependent vortex viscosity of underdoped, Ortho-II YBCO. The measurements reveal a vortex viscosity with surprisingly strong frequency dependence that bears a striking resemblance to the zero-field quasiparticle conductivity. This implies that the dominant dissipative mechanism for the flux lines is induced electric fields coupling to extended, long-lived d-wave quasiparticle states outside the vortex cores, a remarkable upending of the conventional Bardeen-Stephen picture. Analysis of viscosity spectra reveals the presence of a second, shorter timescale in the relaxation dynamics that grows in importance with increasing field, with a dynamical crossover observed in the vortex-liquid regime above which the viscous dynamics have a single, fast relaxation rate. At low temperatures the flux-flow resistivity has a log(1/T) form that is reminiscent of the DC resistivity of cuprates in the pseudogap regime.

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