Experimental Study of a Magnetohydrodynamic Vortex in Gallium: Application to Flow in the Core

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We present experimental measurements of the fluid velocity, induced magnetic field, electric potential and Joule heating in a fluid gallium vortex driven by a rapidly rotating disk and permeated by a transverse magnetic field. The magnetic Reynolds number of the vortex reaches 1.0 at the highest disk speeds. Rotation of the apparatus provides Elsasser numbers (the ratio of Coriolis and Lorentz forces) up to $\Lambda = 1$, comparable to the Elsasser number in the core. The experiments show that Λ is the critical parameter governing the structure of the flow. For $\Lambda \leq 0.2$ the magnetic field reduces the fluid velocity but the vortex remains two-dimensional (geostrophic) due to the influence of rotation. For $\Lambda \geq 0.2$ the Lorentz force breaks the two-dimensionality of the vortex and the flow becomes partly magnetostrophic.
Joule dissipation by electrical (Foucault) currents in the vortex increases approximately as the square of the imposed magnetic field intensity when the vortex is two-dimensional but becomes nearly independent of the magnetic field intensity in the magnetostrophic regime. We derive scaling relationships for Joule heat production in both high and low magnetic Reynolds number regimes. Extrapolation of these relationships the core indicates that Joule heat production is significant in the energy budget of the core, and that Joule heating is large enough to limit the intensity of the magnetic field inside the core.