# Simulation and modeling of the von Kármán sodium experiment

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## Résumé

This study investigates magnetic field generation and dynamics in electrically conducting fluids, a central challenge in planetary and stellar physics. Using the SFEMaNS code, we perform numerical simulations of the Von Kármán Sodium (VKS) experiment, successfully reproducing its main features: an axisymmetric magnetic field exhibiting various dynamical regimes governed by the intensity of asymmetric forcing. Our results identify stable global dipoles, hemispherical dipoles, and reversing magnetic field solutions, providing a detailed description of the inversion mechanism that corroborates existing experimental and theoretical findings. Inversions are characterized as a five-stage sequence: the magnetic field transitions from a dominant dipolar state to a transient quadrupolar configuration, driven by a time lag between the flipping of two localized dipoles near the impellers, before re-establishing the opposite polarity. By simulating a Von Kármán flow generated by rotating iron impellers in a closed cylinder, we identify a hierarchy of four dominant axisymmetric modes: magnetic dipole (D), quadrupole (Q), zonal velocity (V), and symmetric velocity (U), extracted via Proper Orthogonal Decomposition. We then derive a reduced-order DQVU Galerkin model from the governing MHD equations. Explicitly accounting for the high magnetic permeability (mu) of the impellers introduces new first-order couplings that influence both the dynamo threshold - inversely proportional to mu - and the saturation processes via the Lorentz force. The strong mu coupling also highlights a constraint on the selection of the main magnetic mode, which is axisymmetric. Overall, these simulations bridge the gap between simplified toy models and physical experiments, providing a unifying perspective on the VKS dynamo.

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