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Motion and flow of an electrically conducting particle/drop subject to an oscillating magnetic field

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An electrically conducting particle or drop experiences no force or torque in a steady magnetic field. Several interesting effects are observed when an electrically conducting non-magnetic particle experiences a time-varying magnetic field. When there is a rotating particle in a steady magnetic field due to applied shear, oscillating eddy currents are induced in the drop due to Faraday's law[1]. These impart a moment to the particle/drop due to Ampere's law. The cross product of the oscillating magnetic field and eddy current results in a steady component of the force density, which leads to a net torque on the particle when there is rotation. This leads to an antisymmetric part for the stress tensor, which is described by three antisymmetric viscosity coefficients. These result in a rheology modification which is qualitatively different from that for a symmetric stress tensor. When there is a spatially uniform oscillating field acting on an electrically conducting drop, the cross product of the oscillating eddy current and the oscillating magnetic field leads to a steady component of the Lorentz force density[2]. This generates internal circulation in the form of a dipolar flow field and a particle stress. When there is a gradient in the oscillating magnetic field, there is induced current magnetophoresis, that is, movement of an electrically conducting particle down the gradient of the magnetic field magneitude. Expressions for all of these effects depend on the dimensionless parameter ($\beta = \sqrt{\mu_0 \kappa \omega R^2}$), which is the square root of the ratio of the oscillation period and the current relaxation rate in the conductor. Here, (μ_0) is the magnetic permeability, (κ) is the electrical conductivity, (ω) is the frequency and (R) is the particle/drop radius. The characteristic stress generated scales as ($\mu_0 H_0^2/R$), where (H_0) is the magnetic field, and the characteristic velocity is (($\mu_0 H_0^2 R/\eta$)), where (η) is the fluid viscosity.

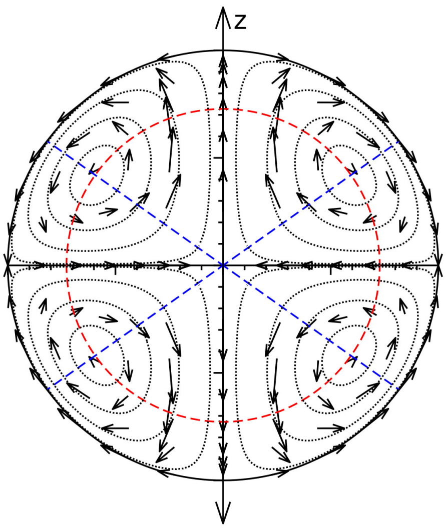

Figure 1: Circulation in an electrically conducting drop due to an oscillating magnetic field.

References

[1] V. Kumaran, J. Fluid Mech., 871, 139-185, (2019).
[2] V. Kumaran, J. Fluid Mech., 1014, A36, (2025).

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