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Electro-rotation of drops at large electric Reynolds numbers

EHUD YARIV, ITZCHAK FRANKEL, Technion — We analyze spontaneous electrohydrodynamic rotation of drops under a uniform electric field by applying the Taylor-Melcher leaky-dielectric model to a two-dimensional system. The dimensionless problem is governed by the ratios of electric conductivities, dielectric permittivities and shear viscosities in the respective drop- and suspending liquid phases as well as the electric Reynolds number R_e quantifying surface-charge convection. We address the asymptotic limit of large R_e where the dominant balance in the boundary conditions results in the flow scaling as $\mathrm{R}_e^{-1/2}$. This flow is governed by a nonlinear boundary-value problem which does not admit a fore-aft symmetric solution, thus necessitating drop rotation. This problem, which is invariant to the inversion of the velocity field, is transformed into a universal one, independent of the conductivity and permittivity ratios. Thermodynamic arguments reveal that a solution exists only when charge relaxation within the suspending liquid is faster than that in the drop. Under these conditions, the rescaled angular velocity is obtained as a function of the viscosity ratio. Comparable numerical solutions, obtained using the exact equations, indeed collapse at large R_e upon the asymptotic universal solution.

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