Streaming-potential revisited

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Electrokinetic streaming-potential phenomena are driven by imposed relative motion between liquid electrolytes and charged solids. Owing to non-uniform convective `surface' current within the Debye layer Ohmic currents from the electro-neutral bulk are required to ensure charge conservation thereby inducing a bulk electric field. This, in turn, results in electro-viscous drag enhancement. The appropriate modeling of these phenomena in the limit of thin Debye layers has been a matter of ongoing controversy apparently settled by Cox's seminal analysis (*J. Fluid Mech.*, vol. 338, 1997, p. 1). This analysis predicts electro-viscous forces resulting from the perturbation of the original Stokes flow with the Maxwell-stress contribution only appearing at higher orders.

Cox's theory is founded upon the assumption of O(1) Hartmann and Peclet numbers. We demonstrate that the product of these numbers actually scales inversely with the square of Debye width and accordingly revisit the generic problem of streaming-potential. Electric-current matching between the Debye layer and the bulk provides an inhomogeneous Neumann condition governing the electric field in the latter. This field, in turn, results in a velocity perturbation generated by a Smoluchowski-type slip condition. Owing to dominant convection, the present analysis yields an asymptotic structure considerably simpler than that of Cox: the electro-viscous effect now appears at a lower asymptotic order and is contributed by both Maxwell and viscous stresses. The present paradigm is illustrated for the prototypic problem of a sphere sedimenting in an unbounded fluid domain with the resulting drag correction differing from that calculated by Cox.