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Emergence of transverse size in electric streamers

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The accurate determination of parameters of electric streamer propagation in air, such as their velocity, transverse size (radius) and the maximum field at the tip, is extremely important, e.g., for the studies of further lightning development and acceleration of electrons at the tip, which may lead to generation of x-rays. Relations between these parameters produce a family of streamer-shaped solutions, while the radius remains undetermined. We hypothesize that all these solutions are, in fact, valid solutions of hydrodynamic equations, but the physical radius emerges when one solution is selected by the condition of being maximally unstable, i.e., having the highest velocity.

Direct verification of this hypothesis by hydrodynamic simulations is complicated by the fact that the streamer length is one of the background conditions which determine its parameters, and in a propagating streamer the length is constantly changing. To circumvent this, we simulate a `steady-state' streamer, such that its length is kept constant by synchronizing the motion of the electrode to which it is attached. We show that the predicted maximally-unstable selected solution does, in fact, emerge in the infinite time limit of the simulation. We note, however, that we were yet unable to test the first part of the hypothesis, i.e. to produce the non-selected solutions in the predicted family, as they are quickly replaced by the selected one.

We present the calculated streamer parameter dependence on external uniform field and streamer length for an isolated streamer and streamers propagating parallel to each other. In the latter case, the field of neighboring streamers makes the streamer propagation independent of its length when it exceeds the inter-streamer distance. We draw parallels of this situation to the selected solution for a viscous Saffman-Taylor finger of infinite length in a narrow channel [Luque et al, 2008, doi:10.1103/PhysRevE.78.016206].

The practical interest of this work lies in reducing the complexity of streamer propagation modeling, by avoiding detailed simulation of the streamer head, if we can calculate the parameters by a simpler algorithm.